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COMPENDIUM ON WATER SUPPLY, DROUGHT, AND CONSERVATION

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COMPENDIUM ON WATER SUPPLY, DROUGHT, AND CONSERVATION

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EXECUTIVE SUMMARY

Ecologists sometimes use a parable known as "the tragedy of the commons" to describe the consequences of overconsuming common resources. At the global level, water is abundant and renewable, but it remains finite as well as nonrenewable in some respects. Water has value principally because its natural characteristics have been altered through withdrawal, treatment, and distribution. Although the reality of absolute scarcity is debatable, perceptions of scarcity and recent events, most notably the 1988 drought, have led to a sense of crisis about water. Escalating prices and the ever intensifying competition for water have probably added to this perception. But while droughts are caused by nature, water shortages are caused by people. In response to a growing awareness of this axiom, the wise use of water may emerge as a guiding principle for water supply management and regulation. An objective, comprehensive, and interdisciplinary approach is essential to the consideration of water resource issues and policies.

Water is part of a grand scheme known as the hydrologic cycle, a closed system in which the same amount of water has been in flux for eons. At present, water supplies on the North American continent are relatively abundant, although water issues in the United States are highly regional because of dramatic differences in water's availability at any given place at any given time. People intervene in the hydrologic cycle to develop water resources for instream and offstream uses. Impairments in water quality or quantity can result either from natural or manmade causes. Members of the scientific community now include global warming on the list of critical water supply problems, and some link changes in the global climate to recurring droughts. Despite the emergence of proposals for large-scale intervention in the hydrologic cycle to increase water supplies, many analysts advocate more efficient management of existing supplies as well as more demand management.

Humans routinely intervene in the hydrologic cycle, borrowing from it to tend to their water needs. This intervention constitutes water demand. The principal offstream water uses are for domestic and commercial purposes, agriculture, industry, and energy development. After decades of steady growth, estimates indicate that a 10 percent reduction in total offstream withdrawals occurred between 1980 and 1985, due in part to improved water

efficiencies, more water reuse, and a reduction of groundwater withdrawals for irrigation. Yet withdrawals for public water supply have continued to rise. In 1985, estimated withdrawals in the United States totaled 338.3 billion gallons of freshwater daily, although only about 27 percent of this water was for consumptive use. Because of uncertainties about future demand and the adequacy of supplies, water demand forecasting is likely to become a prominent and controversial issue in the coming years.

Drought is unique among natural disasters. The creeping and pervasive nature of a drought can make it difficult to define and measure with precision, even retrospectively. Meterological, agricultural, hydrologic, and socioeconomic perspectives on drought and its effects are available. Drought prediction is difficult and the probability of accuracy is only slightly better than chance. Indeed, accepting the inevitability of future droughts and planning for their recurrence may be a more sensible approach. Droughts also are part of a nation's cultural heritage and adjustments to drought can have a permanent effect on lifestyles and behavior. Although severe, the 1988 drought was not as extreme as previous ones. A leading explanation is that the drought was caused by anomalous tropical Pacific Ocean temperatures. Although it left a substantial mark on many regions, the effect of the 1988 drought on the nation as a whole was fairly limited.

Although water shortages tend to generate interest in drought planning, there is an unfortunate tendency toward apathy when supplies are abundant. Yet future droughts are a certainty. Rather than simply reacting to drought through crisis management, a better approach is to anticipate drought and mitigate its effects through risk management. Drought management strategies can target supply or demand and can have either a short- or a long-term time frame. Water suppliers benefit from preparing drought contingency plans and following available planning principles. Absent planning, drought management priorities may be too informal, with water supply managers confining their drought responses to traditional strategies. Many drought management strategies have been shown to be effective in reducing water demand.

Water conservation is one long-term solution to scarcity in the wise-use perspective. Water suppliers can conserve through water loss reductions, pressure reduction, and resource management. Water suppliers also can practice demand management through pricing, user restrictions, and public education. Water users can practice demand management through changes in practices, installation of more efficient appliances and fixtures, use of conservation landscaping, and water recycling and reuse. Conservation programs typically combine supply and demand management strategies. Based on analyses of benefits and costs, even a modest conservation program can yield substantial savings both in terms of water and dollars for most water suppliers. Social acceptability, however, may be a key factor in determining the success of conservation and wise use.

The issue of scarcity raises several issues of state public utility regulation. Prices that accurately reflect costs send correct signals to consumers and discourage wasteful consumption. Marginal-cost pricing has been advanced as a conservation tool. Conservation through pricing is largely a function of the price elasticity of water demand, which is somewhat variable. Some water rate structures (such as increasing block and seasonal rates) are specifically designed for conservation purposes, although disagreement exists over their use. Other regulatory issues on the horizon concern system adequacy, water markets, and least-cost planning for water utilities. More and more public utility commissions are implementing policies that reflect the wise-use perspective. Integrated water resource planning--temporal, spatial, interdisciplinary, institutional, and participatory--may emerge as a new approach to water supply regulation.

Water resource policymaking in the United States is fragmented and pluralistic, so much so that it may appear weak and ineffective. The water supplier today may be accountable to so many governmental authorities that accountability itself is threatened. Governments at all levels formulate policies that affect the issues of water supply, drought, and conservation. Water policy at the federal level is a pluralistic collection of authorizations, appropriations, and administration. The states have primacy in water resource management defined by a system of water law and water rights. Local governments also play a role through municipal water utilities as well as conservation and planning initiatives. There is even a global context to water issues, made evident in proposals for diversions of water to the United States from Canada and Mexico. The abundance of institutional issues makes water resource policy ripe for reform and revitalization. State public utility commissions will continue to play an important part in this process through traditional ratemaking as well as emerging regulatory roles, such as integrated water resource planning.

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FOREWORD

In 1988, the Mid-America Regulatory Conference (MARC) ratified a resolution urging the National Regulatory Research Institute to:

> [A]dopt as a research project a study of issues related to the subject of water policy and conservation in its broadest context. Such a study should include an analysis of the current status of water resources and an analysis of long-term policy and supply for the North American Continent.

This report is in response to the MARC resolution, although it is addressed to all members of the regulatory community and others concerned with the issues of water supply, drought, and conservation.

As we approach the new decade, this study can serve as a vehicle for reviewing policies and priorities, identifying and articulating future goals, and facilitating the implementation process. It should also serve as a valuable information resource for researchers as well as policymakers.

Douglas N. Jones
Director
Columbus, Ohio
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The American Water Works Association merits special thanks for granting permission to incorporate items from their publications in this report, as duly noted. Merrill Publishing Company kindly granted permission to reproduce the illustration of the hydrologic cycle appearing in chapter 2. The authors further acknowledge the U.S. Army Corps of Engineers' Institute for Water Resources and the Congressional Research Service, whose publications were of particular value in researching this report.

These contributions notwithstanding, the authors bear responsibility for the final product.

CHAPTER 1

WATER AND THE THEME OF SCARCITY

Severe drought gripped much of the North American continent in 1988, bringing into focus the concern that water supplies may become increasingly scarce in the future. By the time many analyses of the drought could be published, rain had come to many parts of the country, lessening the sense of fear and, perhaps, lowering the place of water supply issues by a notch or two on the regulatory agenda. Concerns about drought and water supply should not be washed away with the rains, however. Times of abundance should be used to plan for times of scarcity. Saving for dry days is at least as good an idea as saving for rainy ones.

Just how to prepare for dry days is not easily agreed upon. A good starting point may be to address some of the options available to the decisionmakers responsible for water supply management and regulation. This compendium addresses many of the key issues related to drought and water supply based on an extensive review of the literature available on these subjects. It provides a framework for developing public policies toward present and future water planning needs against a backdrop of a perception of scarcity brought about by drought and a variety of other causes.

Water's life-sustaining properties make it a topic for debate that brings out fundamental philosophical, ideological, and, sometimes, emotional points of view. This chapter reviews the intellectual context of contemporary and future water resource issues and policies. Readers may not agree with any or all of the perspectives represented, while still appreciating their relevance to the interdisciplinary water debate. Subsequent chapters address the issues of water supply and water demand, drought and drought planning and mitigation, water conservation, ratemaking and regulation, and federalism. Each subject has significant implications for water supply management and regulation.

Ecology and the Commons

Plato bemoaned the fact that those things common to all members of a society receive the least care. Thomas Malthus in the eighteenth century warned of the perils of overpopulation and the environmental limits on human activity, for which the study of economics earned a reputation as "the dismal science."[1] The degradation of such common resources as water, air, and even the ozone layer are sometimes explained by the lack of self-restraint and the tendency to overconsume common resources. More recently, biologist and human ecologist Garrett Hardin devised a parable for understanding the causes and consequences of overconsumption known as the "tragedy of the commons."[2]

Suppose, Hardin argued, that some farmers graze their sheep on a common meadow. Because the sheep have value, each farmer has an incentive to increase his flock as much as possible. Eventually, the meadow becomes overgrazed, useless to every farmer, and unable to sustain any sheep.

William Ophuls expanded on this logic, emphasizing the problem that people naturally seek to expand their use of "the commons":

> [T]he essence of the tragedy of the commons is that one's own contribution to the problem (assuming that one is even aware of it) seems infinitesimally small, while the disadvantages of self-denial loom large; self-restraint therefore appears to be both unprofitable and ultimately futile unless one can be certain of universal concurrence. Thus we are being destroyed ecologically not so much by the evil acts of selfish men as by the everyday acts of ordinary men whose behavior is dominated, usually unconsciously, by the remorseless self-destructive logic of the commons.[3]

According to the theory, the commons is finite. After reaching its carrying capacity, the commons is destroyed, incapable of sustaining the human activity it once sustained. Absent regulation and protection in the common interest, resources that once were abundant inevitably are exploited until they become ecologically scarce. Thus, collective decisions and authoritative intervention are required if ecological public goods, such as water, are to be provided to the public at large in reasonable amounts.[4]

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[1] Thomas R. Malthus, *Essay on the Principle of Population as it Affects the Future Improvement of Society*, reprinted as *First Essay on Population, 1798* (New York: Kelly, 1965).

[2] Garrett Hardin, "The Tragedy of the Commons," *Science* 162 (1968): 1243.

[3] William Ophuls, *Ecology and the Politics of Scarcity* (San Francisco: W.H. Freeman and Company, 1977), 150.

Indeed, the disciplines of economics and political science thrive on scarcity, the former because of the need for allocation and the latter because of the ensuing conflict over allocation. Paul A. Samuelson emphasizes that, "*What* to produce, *how*, and *for whom* would not be problems if resources were *unlimited*. . . . There would then be no *economic goods*, i.e., no goods that are relatively *scarce*; and there would hardly be any need for a study of economics or 'economizing.'"[5] Similarly, Harold Lasswell defined politics as "*who gets what, when, and how*"[6] and David Easton defined the political system as "the authoritative allocation of something of value for the people as a whole."[7] Herein lies the linkage between scarcity and public policy. Were the commons inexhaustible, neither market allocation (an economic solution) nor collective decisionmaking (a political solution) would not be required.

Water is a natural resource that is increasingly regarded as a potential victim of the tragedy of the commons and therefore one that may require special allocation. According to Ophuls:

> The philosopher David Hume pointed out that if all goods were free, like air and water, any man could get as much as he wanted without harming others. . . . The nature and difficulty of the challenge we confront is apparent from the ironic fact that the very things Hume used to illustrate the state of infinite abundance--air and water--have become scarce goods that must be allocated by political decisions.[8]

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[4] Ophuls, *Ecology*, 146 and 149. Of course, there are other perspectives on public goods.

[5] Paul A. Samuelson, *Economics* (New York: McGraw-Hill, Ninth Edition, 1973), 18.

[6] Harold D. Lasswell, *Politics: Who Gets What, When and How* (New York: McGraw-Hill, 1938).

[7] David Easton, *The Political System* (New York: Alfred A. Knopf, 1953).

[8] Ophuls, *Ecology*, 8-9.

Issues of resource scarcity today frequently are evaluated in global terms. An assessment of the global condition is conducted annually by the Worldwatch Institute.[9] In its 1986 report, the Institute identified "ecological deficits" that occur when "the demands on a natural system exceed its carrying capacity."[10] The result of living beyond existing means is the need to borrow from the future at the cost of future generations. The world's forests, grasslands, fisheries, soil, and oil are natural resources experiencing ecological deficits. The Institute notes that water, too, is becoming scarce in some parts of the world:

> In most situations, scarcity results from a growth in demand that exceeds locally available supplies. In others, it stems from a reduction in supplies, as deforestation, other losses of vegetation, and land degradation increase rainfall runoff, thus reducing both aquifer recharge and evaporation. Reduced aquifer recharge lowers water tables, and reduced evaporation and transpiration may lower rainfall. Countries experiencing a rapid growth in water demand, diminished aquifer recharge, and less rainfall can find themselves in a water crisis almost overnight.[11]

The greenhouse effect is the focus of many contemporary ecologists. In the Worldwatch Institute's 1988 report, Lester R. Brown and Christopher Flavin label the prospect of a changing global climate a "Tragedy of the Commons, writ large" and declare that, "Unless all act together, there is little reason to act separately."[12] While industrialized nations are disproportionately responsible for the climate problem, worldwide increases in carbon emissions require worldwide cooperation. Water resource issues are a central part of concerns about the changing global climate, and scientists increasingly focus on the relationship between climate and hydrology.

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[9] Lester R. Brown, et al., *State of the World* (New York: W. W. Norton, annual).

[10] Lester R. Brown, "A Generation of Deficits," in Lester R. Brown, et al., *State of the World 1986* (New York: W. W. Norton and Co., 1986), 8-11.

[11] Ibid., 10-11.

[12] Lester R. Brown and Christopher Flavin, "The Earth's Vital Signs," in Lester R. Brown, et al., *State of the World 1988* (New York: W. W. Norton and Company, 1988), 20.

Debate over the greenhouse effect, coupled with the recurrence of drought in many parts of the world, has helped to elevate the water issue on the policy agenda. Because the hydrologic cycle is a closed system, there is a greater chance that it will be assessed in terms of the commons and the potential for ecological tragedy.

Water and Scarcity

The tragedy of the commons leads inevitably to the issue of scarcity and the allocation of scarce resources. Modern economists of a Malthusian persuasion, such as Kenneth Boulding, warn of the dismal potential of scarcity to affect future generations:

> [F]ar from scarcity disappearing, it will be the most dominant aspect of the society; every grain of sand will have to be treasured, and the waste and profligacy of our own day will seem so horrible that our descendants will hardly be able to bear to think about us.[13]

Scarcity is a more common condition than abundance for most goods, particularly in modern societies. Certainly scarcity is an attribute of most natural resources and an issue that societies regularly confront.[14] In fact, most economists would argue that when it comes to scarcity, the relevant concern is the market's determination of price and quantity supplied. The perception of scarcity is thus based on the effects of higher prices for a commodity that is increasingly difficult to come by. In reality, political, social, institutional, and other forces can make scarcity a very real policy issue. Perceptions of water scarcity, in particular, can evoke a somewhat emotional response as well:

> Scarcity. . . . is a relative and variable condition which characterizes most natural resources in most settings. Scarcity is the foundation stone of all economic markets--a common condition in trade and commerce. With response to water, however, scarcity somehow takes on the aura for the

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[13] Kenneth E. Boulding, "Is Scarcity Dead?," *Public Interest* 5 (1966): 36-44.
[14] Kenneth D. Frederick, "Overview," in Kenneth D. Frederick, ed., *Scarce Water and Institutional Change* (Washington, DC: Resources for the Future, 1986), 19.

> public of extreme deprivation or threatened disaster, even when conditions only suggest that no more free or cheap water is available.[15]

Indeed, scarcity and crisis are among the most frequently used characterizations in contemporary studies of water issues. Globally, water is a plentiful resource with an enormous carrying capacity. Unlike the common meadow, it is difficult to imagine its obliteration. But even plentiful resources are finite and can become scarce anytime and anyplace. The *Global 2000 Report to the President* noted in 1980 that the world's supply of freshwater was ten times greater than demand, but that by the year 2000 supply would be only 3.5 times demand, dramatizing "the rapidity with which human demand is catching up with the world's theoretical availability of freshwater."[16] The report also emphasizes that even these projections can be misleading when the extreme seasonal and geographical unevenness in the distribution of water resources is taken into account. Local and regional deficiencies in water supplies occur on a seasonal and, increasingly, perennial basis.

In another study, the Worldwatch Institute points out that water rationing in the middle 1980s was implemented in cities vastly different in climate: Newark, New Jersey; Corpus Christi, Texas; Managua, Nicaragua; and Tianjin, China. According to analyst Sandra Postel, "Water planners in many corners of the world--in humid climates as well as dry, in affluent societies as well as poor ones--are projecting that within two decades water supplies will fall short of needs" at present rates of use.[17]

In the United States, conditions of scarcity can be found in virtually every region of the country at one time or another, but are especially pervasive in the West and Southwest. Kenneth D. Frederick and Allen V. Kneese point out that, "The transition to conditions of water scarcity has been under way for several decades in some areas of the West."[18] Conflict may be exacerbated by the pluralistic nature of government policy toward water and the many layers of government involved. Conflict over water in the Southwest is a case in point:

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[15] Gary Weatherford, "Thematic Overview of the Conserve-and-Transfer Strategy of Water Management, in Gary D. Weatherford, ed., *Water and Agriculture in the Western U.S.: Conservation, Reallocation, and Markets* (Boulder, CO: Westview Press, 1982), 3-4.

[16] Gerald O. Barney, *The Global 2000 Report to the President of the U.S.: Entering the 21st Century* (New York: Pergamon Press, 1980).

[17] Sandra Postel, "Increasing Water Efficiency," in Brown, et al., *State of the World 1986*, 40.

> [T]he scarcity of water in the Southwest has led to the evolution of a complex set of legal and political institutions governing the use of that water. There remain many important unresolved questions about the adequacy of these institutions and the scope of their separate jurisdictions. When projected demands for Southwest water are set down amid this institutional complexity, the basis for conflict is laid.[19]

The alarm associated with water scarcity may have less to do with the idea that water resources are exhaustible than with the problem that new supplies are not guaranteed. The high cost of some new supplies may pose a barrier to their development. Even the availability of low-value or underutilized supplies can be a problem because institutional factors may restrict transfers or otherwise discourage efficient allocation. For example, water resource development in some areas may be impaired by persistent uncertainties about water rights.

Scarcity affects regions as well as individuals. Long-term conditions of scarcity, for example, can impair economic development. On the other hand, the abundance of water can provide a region with a locational advantage over other regions experiencing scarcity. Some would argue that water-rich regions should not transfer this resource (assuming this would be technologically and economically feasible), but should exploit water resources as a tool of economic development.

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[18] Kenneth D. Frederick and Allen V. Kneese, "Competition for Water," in Kenneth D. Frederick and Allen V. Kneese, eds., *Competition for Water* (Washington, DC: Resources for the Future, 1984). In another study, Zach Willey concludes that "Scarcity is at the root of California's water conflicts." *Economic Development and Environmental Quality in California's Water System* (Berkeley, CA: University of California, Institute of Governmental Studies, 1985), 2.

[19] Allen V. Kneese and F. Lee Brown, *The Southwest Under Stress: National Resource Development Issues in a Regional Setting* (Baltimore: Resources for the Future and Johns Hopkins University Press, 1981), 3.

Thus, even if water is globally plentiful, it may become increasingly difficult to acquire in some areas. As Gary Robinette observes:

> The entire water supply on the planet earth is a closed system. Water changes form and location, not always in the form and in the location we desire, but almost no water which has existed on the earth has ever disappeared. . . . Basically water is almost always available, but the cost may prohibit using it in the traditional way. Water, which was once thought to be free and plentiful, will become increasingly expensive as man is required more and more to interfere in and modify the water cycle.[20]

Finally, part of the problem in separating myth from reality with respect to water scarcity is the issue of renewability. As Kenneth D. Frederick observes, "While the hydrological cycle makes water a renewable resource, it also makes it *fugitive* in time and space."[21] And in fact, some water comes from highly constrained or nonrenewable sources, as in the case of groundwater supplies where overdrafts or pollution have exceeded nature's capacity to renew.[22] Moreover, treated water for drinking and other purposes is not a naturally renewable resource.[23] The hydrologic cycle continuously replenishes natural water resources but does not automatically deliver water free from impurities in unlimited quantities at a given source and at a given time.

Donald L. Schlenger and Thomas W. Cervino argue that utility-supplied water has value because its "temporal, spatial, and physiochemical characteristics have been altered."[24] The delivery of water of acceptable quality and quantity requires manpower, energy, chemicals, and physical facilities, all of which are composed of nonrenewable and energy-intensive materials. Thus, water suppliers can be properly regarded as value-added carriers. Even self-supplied water requires an investment of resources. Increasingly stringent federal and state water-quality regulations will add to drinking water's value as a nonrenewable resource because of the often high costs of compliance. Particularly when there is a perception that *drinking* water supplies are scarce, perceptions of a water crisis are highly probable.

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[20] Gary O. Robinette, *Water Conservation in Landscape Design and Management* (New York: Van Nostrand Reinhold Company, 1984), 8.

[21] Kenneth D. Frederick, "Water Policies and Institutions," in David H. Speidel, Lon C. Ruedisili, and Allen F. Agnew, eds., *Perspectives on Water: Uses and Abuses* (New York: Oxford University Press, 1988), 335. Emphasis added.

[22] Jan Van Schifgaarde and George J. Kriz, et al., "Water: A Basic Resource," in William E. Larson, et al., eds., *Soil and Water Resources: Research Priorities for the Nation* (Madison, WI: Soil Science Society of America, Inc., 1981), 1.

[23] Donald L. Schlenger and Thomas W. Cervino, "Water Conservation Rationales: Are There Historical Parallels?," *American Water Works Association Journal* 72, no. 1 (January 1980): 37-38.

[24] Ibid.

Does a Water Crisis Exist?

Perceptions of scarcity, caused by high prices or other conditions, can lead to perceptions of crisis. More than one water supply analyst has concluded something to the effect that unless we change our ways, a water crisis is inevitable.[25] However, it may be, as Robert W. Harrison argues, that the term "crisis" has been greatly overused in conjunction with water supply issues:

> The word "crisis" has often been used in relation to water problems, but after 1974 it became almost a standard prefix, applicable to both supply and quality. The "water crisis" was compared to the "oil crisis." It was observed that the price of bottled water was higher than the top grades of gasoline! All of this was to a considerable degree the product of "journalism" and had little relation to real [life] water problems, but it was and is in a dramatic way a reminder that uncertainty and a feeling of insecurity is now widespread when it comes to the water resource.[26]

As Harrison implies, the water supply crisis appears linked to other modern "crises." After all, diverting water from its natural course in the hydrologic cycle requires energy, and higher energy prices in the wake of the energy crisis increase the cost of pumping, diverting, treating, and transporting water. Economic crises, characterized by inflated prices, bring attention to rising costs in general, including the cost of water supply. The enactment and implementation of more stringent drinking water standards contribute to a sense of crisis about water quality and safety. The quality and quantity of water supply both may be impaired by modern ecological crises, such as oil spills, acid rain, and other forms of environmental pollution. Global warming may be the foremost crisis at the close of the 1980s. It, too, is linked to the water supply crisis as the scientific community strives to assess the connections between global climate and hydrology, and the impact of humans on both.

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[25] Terry L. Anderson, *Water Crisis: Ending the Policy Drought* (Washington, DC: CATO Institute, 1983), 4.

[26] Robert W. Harrison, "Water Supply and Water Quality Studies in the Institute for Water Resources U.S. Army Corps of Engineers," in James E. Crews and James Tang, eds., *Selected Works in Water Supply, Water Conservation and Water Quality Planning* (Fort Belvoir, VA: Institute for Water Resources, U.S. Army Corps of Engineers, 1981), 25.

Perceptions of crises, however, must be distinguished from actual conditions. Journalists, for example, can sometimes create a perception of crisis simply by using the term, even when the facts do not support this characterization.[27] Interest groups sometimes create a perception of crisis by publishing reports that grab the attention of both the public and policymakers. Politicians sometimes create a perception of crisis in the course of election campaigns. Even governments can create a perception of crisis by spending millions, even billions, of dollars formulating policies, programs, and projects. Thus, some observers, such as Frank Welsh, conclude that the water crisis actually is a man-made phenomenon:

> [T]he water crisis is the creation of man, not nature. It is the result of shortcomings in human rules and regulations, not nature's resources. Rather than change their institutions and letting the market place work, local entities have looked to big government to solve their self-imposed crises. Politicians and bureaucrats have been only too willing to exploit the void and further compound the crisis.[28]

Of course, actual events contribute to perceptions. Droughts, for example, pose real threats to water supplies by temporarily reducing carrying capacities. Agriculture, navigation, wildlife, and other areas also are threatened in real terms. There is a growing awareness, moreover, that nature alone cannot be blamed for temporary water shortages. While having adequate supplies is in part a function of nature (and being in the right place at the right time), water shortages are a function of both supply and demand. As James Krohe, Jr. observed:

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[27] During drought periods, all of the major news media devote stories or entire series to the water crisis. Media attention to drought, however, is generally beyond the scope of this investigation.

[28] Frank Welsh, *How to Create a Water Crisis* (Boulder, CO: Johnson Books, 1985), 192.

> The prospect of water shortages in a region which is within spitting distance of the largest fresh water lake system in the world seems not merely ironic but insane. But the water problems of northeastern Illinois illustrate one of the axioms of the water business, which is that while droughts are caused by nature, water shortages are caused by people.[29]

There is also an emerging concern about the capability of people and institutions to plan and manage water resources to assure adequate future supplies. According to Albert W. White, "The likelihood of the world running out of water for sustaining its life is zero; the likelihood grows of its grossly mismanaging its water resource unless the proper political and technological decisions are made."[30] Thus, some of the more pessimistic water resource analysts not only blame mankind for water resource problems, but also have little faith that policymakers will be capable of finding solutions to those problems.

Crises and crisis management may have negative effects, including a potential to distort decisionmaking processes. Some of the more extreme proposals for new sources of water supply, are provocative, if expensive and impractical, and include towing icebergs and desalting the oceans.[31] John R. Shaeffer and Leonard A. Stevens emphasize that such solutions are aimed at the wrong end of the problem and that the solution to the water crisis will not be found in the search for new supplies but in the efficient management of existing supplies.

On the other hand, a crisis--perceived or otherwise--elevates issues to a higher position on the public and policy agendas, greatly enhancing the chance that decisionmakers will do something about them. Although the characterization of the current situation as a crisis is a debatable point, water issues have become more visible and there is an emerging consensus on the need to address long-term water needs. Of course, how an issue gets on the agenda may be less important than the fact that it gets there at all. Whether or not one believes that a water crisis is imminent (due to climatic change, man-made causes, or simply high prices), preparing for scarcity is likely to have a positive effect on water resource management and planning.

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[29] James Krohe, Jr., *Water Resources in Illinois: The Challenge of Abundance* (Springfield, IL: Illinois Issues, 1982), 13.

[30] Albert W. White, "Water Resource Adequacy: Illusion and Reality," in Speidel, Ruedisili, and Agnew, eds., *Perspectives on Water*, 19.

[31] John R. Schaeffer and Leonard A. Stevens, *Future Water: An Exciting Solution to America's Most Serious Resource Crisis* (New York: William Morrow and Company, 1983), 15.

The Competition for Water and Water Pricing

Analysts have begun to recognize the intensifying competition for water that exists among uses, users and locations, and over time.[32] The competition for water has further intensified with the awareness that some local water resources can reach their carrying capacity, despite the vast quantity of water in the entire hydrologic system. According to John Bredehoeft:

> On the average, the quantity of water in transport in the hydrologic cycle remains unchanged. Except for the fact that we are mining groundwater, no less water is available than heretofore. The fact that we are approaching the limit of the water which can be developed means that there is, and will continue to be, ever-increasing competition for that water.[33]

As another observer notes, "There is not necessarily a lack of water; there is a competition for available water resources."[34] The principal competitive water uses are: domestic, commercial, and industrial use, irrigation, recreation, wildlife habitat, navigation, and energy production. Competition intensifies when water supplies are altered or impaired by environmental, institutional, or economic conditions. The competition for water "can be direct and obvious, as in the case of barges versus fishermen or among irrigators, or it can be indirect and subtle, as in the case of acid rain."[35]

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[32] K. William Easter, Jay A. Leitch, and Donald F. Scott, "Competition for Water: A Capricious Resource," in Ted L. Napier, et al., eds., *Water Resource Research: Problems and Potential for Agriculture and Rural Communities* (Ankeny, IA: Soil Conservation Society of American, 1983). See also Frederick and Kneese, *Competition for Water*.

[33] John Bredehoeft, "Physical Limitations of Water Resources," in Ernest A. Engelbert and Ann Foley Sheuring, eds., *Water Scarcity: Impacts on Western Agriculture* (Berkeley, CA: University of California Press, 1984), 43.

[34] Robinette, *Water Conservation in Landscape Design*, 8.

William Easter, Jay A. Leitch, and Donald F. Scott point out that the degree to which water uses compete with or complement one another, is highly sensitive to climatic conditions:

> Drought years heighten the competition for water between irrigators and navigational users. Wet years heighten the competition between drainage enterprises and downstream floodplain residents. In the first instance the competition is expressed in competing claims for receiving water, but in the second the claims involve disposal of excessive water.[36]

Regional examples of the competition for water are plentiful. In the Pacific Northwest, along the Columbia and Snake Rivers, the competition for water among divergent uses can be intense.[37] Offstream uses include the provision of domestic water supply for eight million people as well as irrigation of nearly nine million acres of land. Instream uses include fifty-nine Columbia River-system dams providing 110 billion kWh in firm capability and 35 billion kWh in secondary capability, the latter depending on adequate stream flows. Instream uses also include the annual passage of eight million tons in barge transportation and the daily passage of 800,000 salmon and steelhead fish.

One of the most notable historical examples of direct competition concerned the use of Lake Michigan as both a source of drinking water for the City of Chicago and as a receptor of the city's wastewater.[38] In the wake of an 1885 typhoid and cholera epidemic that claimed 12 percent of the city's population, engineers reversed the Chicago River's flow so that waste would pass to the Illinois River and eventually to the Mississippi River.

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[35] Easter, Leitch, and Scott, "Competition for Water," in Napier, et al., eds., *Water Resource Research*, 152.

[36] Ibid.

[37] Pacific Northwest River Basins Commission as reported in Walter R. Butcher and Philip R. Wandschneider, "Competition Between Irrigation and Hydropower in the Pacific Northwest," in Kenneth D. Frederick, ed., *Scarce Water and Institutional Change* (Washington, DC: Resources for the Future, 1986), 29.

[38] Ibid., 140.

The diversion caused a series of spillover effects, both positive and negative. Reduced Great Lakes water levels impaired navigation and hydroelectric power production, but may have reduced shoreline erosion in some areas. Navigation and power production were enhanced on the Illinois River by increased streamflows, but downstream flooding increased and recreational potential was reduced. In a common-law suit spanning more than four decades (1925-1967), initiated by riparian states on the Great Lakes, the U.S. Supreme Court ruled that Illinois must limit its lake withdrawals.[39] Since then, especially in drought years, navigation users continue to press for more diversions of lake water to the Mississippi River. The debate among competing interests and institutions, however, has had an almost paralyzing effect on policymaking for the Great Lakes region.

The competition for water has direct implications for public policy in the area of water supply. According to the Water Resources Council, "With ever increasing offstream and instream demands being placed on the Nation's water resources, it must be recognized that competition for water is a fact."[40] Solutions, the Council suggested, must involve tradeoffs, which may result in some water use restrictions that, in turn, limit development.

Scarcity and competition for water inevitably raise the issue of price and the adequacy of existing pricing mechanisms. As Charles Foster and Peter Rogers observe:

> [Q]uestions about water *pricing*--for irrigation, for commercial and industrial uses, for municipal water supply, and even for environmental and recreational purposes--loom large on the horizon. At a time when the federal deficit has never been higher, there is an urgent need to more closely balance water expenditures with water revenues. The questions become crucial as the useful lifetime of many aspects of the water infrastructure draws to a close.[41]

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[39] C. W. Fetter, *Applied Hydrogeology* (Columbus, OH: Merrill Publishing Co., Second Edition, 1988), 455. On the issue of water rights, see chapter 9.
[40] U.S. Water Resources Council, *The Nation's Water Resources, 1975-2000, Volume 1: Summary* (Washington, DC: U.S. Water Resources Council, 1978).
[41] Charles H. W. Foster and Peter P. Rogers, *Federal Water Policy: Toward an Agenda for Action* (Cambridge, MA: Energy and Environmental Policy Center, John F. Kennedy School of Government, Harvard University, 1988), 41.

According to economic theory, scarce goods should command a higher price and, conversely, higher prices should cause less consumption. Indeed, economist Paul A. Samuelson once used a water consumption metaphor to illustrate the mechanics of price and demand in relation to conditions of scarcity and abundance:

> When water is very dear, I demand only enough of it to drink. Then when its price drops I buy some to wash with. At still lower prices, I resort to still other uses; finally, when it is really very cheap, I water flowers and use it lavishly for any possible purposes.[42]

The economic value of water lies not in the water itself but in the processes required to withdraw it from natural sources and deliver it in sufficient quantities and of acceptable quality to the consumer. No real substitutes for water exist, only variations in its quality and methods of delivery. The most frequent criticism of water pricing is its underpricing, which in turn sometimes is blamed for the wasteful use of water. Dean Mann emphasizes that the "scarcity value" of water should play a role in determining its price, in this case for irrigation:

> The problem with current pricing is that the price does not reflect the cost of supplying water and the willingness of individuals to pay for water in terms of scarcity value. The tendency, then, is for users to take more water than the real social value of water should warrant. If water were priced at its true scarcity value, it is argued, farmers would tend to use the water more efficiently--both in the technical and economic sense of the word.[43]

The pricing issue is intrinsically related to the issue of water use and competition. When water is abundant (and inexpensive), many alternative uses can be satisfied; when water is scarce (and costly), tradeoffs must be made. In most regions of the country, there are many alternative uses for water resources. The tension among water users during times of scarcity (such as during a drought) can run high, and high prices can aggravate the situation. In most areas, water markets are ill-defined and layered with laws, interest groups, and institutions that complicate the pricing issue.

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[42] Paul A. Samuelson, *Economics: An Introductory Analysis* (New York: McGraw-Hill, Seventh Edition, 1967), 60.

[43] Dean Mann, "Opportunities for Water Conservation," in Weatherford, ed., *Water and Agriculture*, 25.

As Bredehoeft explains, when water uses compete, the problem is not necessarily a shortage of water in the hydrologic system but a shortage of cheap water:

> Increased competition implies a higher value for the commodity. While as a society we rarely make large-scale water decisions purely on economic grounds, higher value also implies a higher price. Thus, in the context of increased competition, we have a shortage, at least of inexpensive water.[44]

At higher prices, the motivation to conserve is also higher. In the competition for water, water users not only have an interest in their own ability to conserve, but in the ability of others to conserve so that more water is available for their own use. A study by the Congressional Research Service contends that small diversions from agriculture can meet projected municipal and industrial water demand in the water-short West without displacing agriculture "if exchanges are accompanied by increased efficiency in agricultural water use."[45] One book about water scarcity in agriculture, on the other hand, includes a chapter on increasing efficiency in nonagricultural water uses.[46]

Several analysts emphasize the use of pricing as a conservation tool in the interest of the more efficient allocation and use of scarce water resources:

> [W]ater is. . . . a resource that may be developed or conserved on the basis of the benefits and costs to society. Greater technical efficiency may be achievable and water may be put to additional uses, but the question is whether it is economically efficient for society or for the individual farmer to make the necessary investments to do so. Conservation may be accomplished by pricing water at its

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[44] Bredehoeft, "Physical Limitations," in Engelbert and Sheuring, eds., *Water Scarcity*, 43.

[45] John L. Moore, et al., *The Nation's Water Supply: An Overview of Conditions and Prospects* (Washington, DC: Congressional Research Service, Library of Congress, 1986), iv.

[46] Engelbert and Scheuring, eds., *Water Scarcity*.

> marginal value in a market that provides for transfers of water to its highest uses.[47]

On the other hand, some will argue that price is not an appropriate allocation tool during a severe water shortage because of the potential for inequity as well as physical harm. As one group of scholars noted, "After the air we breathe, water is the first requirement for human existence and, therefore, in the ultimate, cost cannot be the only criteria [sic], and drought control by price cannot be a major factor."[48] Those who will not advocate the sole use of price must find alternative allocation methods.

Whether or not it is used for conservation or drought control purposes, water pricing is central to future supply planning. In fact, the sense of water scarcity may be a crisis of pricing and planning as much as anything else. When water resources are undervalued, investments in their development may be misallocated or fall short of needs altogether. As the days of cheap water draw to a close, the water debate will be shaped by the ability and willingness of different users to pay for this increasingly scarce resource. Those who are unable or unwilling to pay for water at higher prices may choose conservation as a way to keep costs down. In a genuine water crisis, they may have no choice but to conserve.

Conservation and the Wise Use of Water

As water becomes more scarce, more expensive, or both, conservation gets more attention. But conservation, like scarcity, means many things to many people and there is no universally accepted definition of water conservation.[49] Dictionary definitions are not necessarily helpful. Most emphasize the preservation and protection of a natural resource. Debates over definitions can be a matter of semantics, and may not prove to be productive. On the other hand, such debates are not entirely academic. Alternative definitions of conservation frequently reflect underlying conflict over goals. Because they suggest public policy alternatives for water use and supply, they also are central to the policymaking process.

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[47] Dean Mann, "Institutional Framework for Agricultural Water Conservation and Reallocation in the West: A Policy Analysis," in Weatherford, ed., *Water and Agriculture*, 12-13.

[48] David R. Dawdy, L. Douglas James, and J. Anthony Young, "Demand Oriented Measures," in Vujica Yevjevich, Luis da Cunha, and Evan Vlachos, *Coping with Droughts* (Littleton, CO: Water Resources Publications, 1983), 164.

[49] William O. Maddaus, *Water Conservation* (Denver, CO: American Water Works Association, 1987), 5.

Part of the problem in defining conservation is that so many activities seem to qualify. The proposed Municipal and Industrial Water Conservation Act of 1989, for example, defined water conservation as "any beneficial reduction in water use or water losses."[50] William O. Maddaus points out the diversity of water conservation methods, which include the development of maximum dependable yields, watershed protection, water loss reduction, universal metering, the use of efficient fixtures, and public education programs.[51]

In 1980, the U.S. Water Resources Council defined water conservation as activities designed to reduce the demand for water, improve efficiency in use and reduce losses and waste of water, or improve land management practices to conserve water.[52] The American Water Works Association has defined water conservation as a way to solve many water supply problems, either through supply management (in which the water utility conserves water) or through demand management (in which the consumer conserves water).[53] Similarly, Mark J. Hammer sees water conservation as either a reduction in consumer water usage or a reduction in water losses, both of which would be carried out in order to reduce water demand, reduce water and wastewater processing costs, and slow the depletion of a limited water supply.[54]

Each perspective on water conservation has a slightly different emphasis. In a particularly useful classification, Dean Mann identifies four contemporary perspectives.[55] The first links water to use and development, emphasizing that water not used is wasted. In this view, traditional economic efficiency goals are secondary to goals of growth and development. The second takes an opposing view emphasizing the principle of preservation. Aesthetic, ecological, and naturalist goals take precedent over other uses and management purposes. A third definition is more technical and emphasizes efficiency in the hydrological sense. Conservation efforts in this area, including more efficient irrigation practices, target the reduction of water losses caused by evaporation, transpiration, drainage, or pollution. The fourth perspective emphasizes conservation from an economic efficiency standpoint. The use of water markets, marginal-cost pricing, and cost-benefit analysis for water resource projects are all consistent with the idea that water is wasted or misallocated because prices do not adequately reflect its value. Accordingly, the degree to which water either is developed or conserved should be determined by market mechanisms, not direct intervention, and barriers to market reliance should be removed.

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[50] "Municipal and Industrial Water Conservation Act of 1989," Senate Bill 1422, *Congressional Record*, Vol. 135, No. 103, 27 July 1989.

[51] Ibid.

[52] "Guidelines for State Water Management Planning," *Federal Register*, 21 July 1980, as reported in Maddaus, *Water Conservation*, 5.

[53] American Water Works Association, *Before the Well Runs Dry, Volume I--A Handbook for Designing a Local Water Conservation Plan* (Denver, CO: American Water Works Association), 6-7.

[54] Mark Hammer, *Water and Wastewater Technology* (New York: John Wiley & Sons, Second Edition, 1986), 324.

Peter E. Black draws upon resource economics for a conservation definition that emphasizes slowing rates of resource use; in other words "shifting rates of use towards the future."[56] Black contends that conservation is a way of controlling use over time for people's benefit. Thus, conservation is neither exploitation (through immediate consumption) nor preservation (through indefinite postponement of consumption). Instead conservation is the entire spectrum of consumption. According to Black, conservation is a "balance of policies, programs, plans, projects, and practices that run the gamut from exploitation to preservation in order to manipulate (manage) the rate of using natural resources in the interest of mankind."[57]

The idea of the "wise use of water" has been advanced by many analysts and policymakers as the best way to avert a water crisis. Indeed, "wise management" and "efficient use" are central themes of water conservation legislation recently proposed in Congress.[58] The wise-use concept combines advances in the technology and management of water supplies with changes in attitudes toward water consumption, particularly with respect to wasteful activities and behaviors. As Warren Viessman, Jr. explains:

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[55] Dean Mann, "Introduction and Context," in Weatherford, ed., *Water and Agriculture*, 12-13.

[56] Peter E. Black, *Conservation of Water and Related Land Resources* (New York: Praeger Publishers, 1982), 156.

[57] Ibid., 157.

> In the final analysis, the severity of water and other crises we may face as a nation will depend heavily upon our ability to be "society wise" as well as "technology wise." If we can do this, our creativity, imagination, and solid technical underpinning will find a way to unlock the constraining mechanisms that force users to operate at a level of efficiency far beneath that for which we are capable. . . . This is the challenge, and if it is not accepted, the frequently referred to "water crisis" will become a reality.[59]

The wise-use concept has emerged as a perspective on water conservation that has appeal because it encompasses efficiency goals without necessarily discouraging the use of water as appropriate and necessary. Thus it does not preclude the development of water resources, as long as they are justifiable in terms of wise use. In this respect, wise-use definitions go further than some others in integrating supply and demand for the purposes of water resource management and regulation.

Schlenger and Cervino emphasize that because drinking water is a nonrenewable resource, it merits conservation, that is, "wise, efficient use." According to these authors, progressive definitions consider conservation in terms of planned management or wise utilization of the resource. They also criticize the tendency to approach water conservation in terms of rationalization rather than "the carefully, considered intelligent approach it deserves."[60]

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[58] "The Municipal and Industrial Conservation Act of 1989," Senate Bill 1422 (H.R. 3099), *Congressional Record*, Vol. 135, No. 103, 27 July 1989.

[59] Warren Viessman, Jr., "Water Crisis: A Physical Reality or an Institutional Specter," Appendix C in U.S. Army Corps of Engineers and Pennsylvania Bureau of Water Resources Management, *The State of the States in Water Supply/ Conservation Planning and Management Programs* (Fort Belvoir, VA: Institute for Water Resources, U.S. Army Corps of Engineers, 1983), C-4.

[60] Schlenger and Cervino, "Water Conservation Rationales," 37-38.

James C. Wade also provides a wise-use definition that emphasizes preserving water resources for future generations as well as balancing the needs of different water users:

> Conservation is the wise use of society's natural resources for present and future generations. Through individual decisions, negotiations, and legislation society makes resource choices and sets conservation policies. In this context, conservation decisions reflect society's attitudes toward and strategies for using natural resources in production, recreation, and culture.[61]

Finally, the U.S. Water Resources Council extended its wise-use definition to encompass a public-interest perspective:

> The goal of water conservation is to avert critical water shortages and to get the greatest use from existing supplies. If better management and technology can reduce water withdrawals while producing the same services, the efficiency of water use (output produced for each unit of water) can be increased. Although improvements in water management and technology will be constrained by costs and other considerations, conservation efforts can focus on technologies to reduce water requirements. . . . Neither "availability" nor "requirements" should be treated as unalterable in water conservation. Technology and management can bring supply and demand into balance in the best public interest. The challenge for water conservation is to ensure the best allocation of available supplies among users.[62]

The wise-use principle will continue to play a role in shaping choices about water supply. However, the extent of its role will depend largely on how the perceptions of policymakers, not only in times of scarcity but in times of abundance. The regulatory agenda, too, will be affected by water issues--supply, drought, and conservation--more than ever before.

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[61] James C. Wade, "Efficiency and Optimization in Irrigation Analysis," in Norman K. Whittlesey, ed., *Energy and Water Management in Western Irrigated Agriculture* (Boulder, CO: Westview Press, 1986).

[62] U.S. Water Resources Council, *The Nation's Water Resources 1975-2000, Volume 1: Summary*, 21.

Scarcity, Public Policy, and the Regulatory Agenda

According to Robert W. Harrison, "Much can be learned about the values placed on the uses of water by studying the response different types of communities make to water shortage and fear of shortage."[63] The same can be said for state governments and nations as a whole. At one time or another, every corner of the world experiences a shortage of water. For some, scarcity is a perennial problem.

As already discussed, the characterization of the current situation as a crisis is at least debatable. Yet the overwhelming view is that water supply issues in the United States require serious attention. Some advocate fundamental changes to how mankind views water resources, not just here but worldwide. Wise use, or a variation on this theme, may emerge as the new paradigm, or guiding principle, for water supply management and regulation. Conservation and integrated water resource planning are among the policies that are generally consistent with the idea of wise use.[64] A report published by the World Meteorological Organization is prefaced with the remark that:

> [M]an has begun to realize that he can no longer follow a "use and discard" philosophy--either with water resources or any other natural resources. As a result, the need for a consistent policy of rational management of water resources has become evident.[65]

Charles H. W. Foster and Peter P. Rogers conclude that, "the dominant water problems are not those of supply, but rather of availability, management, and usage--matters affected by water *policy*."[66] Some critics characterize United States water policy--if there is one at all--as one of crisis management.[67] Droughts come and policymakers shift into a crisis mode. Droughts pass and business-as-usual resumes. Little attention is paid to water-shortage issues during the interim when water is relatively abundant.

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[63] Harrison, "Water Supply and Water Quality Studies," in Crews and Tang, eds., *Selected Works in Water Supply*, 34.

[64] That is, all conservation and planning policies do not constitute wise use simply by definition. Such fine distinctions, however, are not essential to this analysis.

[65] M. A. Beran and J. A. Rodier, *Hydrological Aspects of Drought* (Paris, France: UNESCO and The World Meteorological Organization, 1985), iii.

[66] Charles H. W. Foster and Peter P. Rogers, *Federal Water Policy: Toward An Agenda for Action* (Cambridge, MA; Energy and Environmental Policy Center, John F. Kennedy School of Government, Harvard University, 1988), 1.

Governments at the federal, state, and local levels have begun to take note of water supply, drought, and conservation policy issues. These same issues also are making their way onto the already complex and demanding agendas of public utility commissions that recognize the potential for jurisdictional water utilities to be affected by occasional or perennial water shortages.

Issues of water supply and conservation may appear before regulatory bodies in a number of different forms. Rate cases may address the merits of alternative approaches to pricing. Water supply cases may consider conservation practices, including pricing reforms, as alternatives to building new sources of supply. Commissions or other parties may initiate rulemakings to address such issues as least-cost water supply planning and drought planning. Management prudence and financial decisions affecting future supplies may be evaluated in the course of audits or other regulatory proceedings.

Policy choices in the water resource field are vast and varied; many are tied to particular disciplines. Economists may advocate pricing reform. Engineers may advocate development of new supplies. Attorneys may advocate revisions in the system of water rights. Risk managers may advocate drought contingency planning and mitigation measures. Proponents of wise use may advocate conservation and integrated water resource planning, and so on. Many of the parameters of these choices are addressed in this report.

Whether or not one subscribes to a scarcity theory, a crisis scenario, a resource competition model, or any other systematic assessment of today's global water condition (and regardless of how one defines the concept of conservation), the time is ripe for water supply regulators to develop their own perspective on the issues. Rather than react to existing conditions or to other players' actions in the regulatory system, they may choose to actively address the issues in a manner suitable to both the traditions and principles of public utility regulation as well as to the demands of current policy issues. The public-interest standard so central to public utility regulation seems quite appropriate for decisions about water supply, particularly when a tragedy of the commons becomes possible.

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[67] Donald A. Wilhite and William E. Easterling, eds., *Planning for Drought: Toward a Reduction of Societal Vulnerability* (Boulder, CO: Westview Press, 1987), preface.

Regulatory commissions are routinely challenged to test new limits of knowledge and technical expertise. There is no reason to believe that commissions are any less capable of dealing with complex water issues as with any other complexity of regulation. If anything, the commissions are well positioned to place water supply issues on the regulatory agenda and keep them there not only in times of scarcity, but in times of abundance as well.

CHAPTER 2

WATER SUPPLY

The supply of water is part of a grand scheme known as the hydrologic cycle. While the total global quantity of water remains constant, great fluctuations occur in the level of supply at any given place at any given time. As already discussed, many current assessments of water supply emphasize the prospect of scarcity; some even warn of an impending water crisis. As will be seen in chapter 3, the components of water demand can be divided into use categories that compete, directly or indirectly, for the earth's water supplies. In fact, the withdrawal of water from natural sources is normally associated with specific water-use categories.

Most analysts recognize the symbiotic relationship between supply and demand when seeking to explain the causes and effects of water scarcity.[1] For water, both supply and demand are influenced by natural and artificial circumstances. This chapter concerns water supply--where water comes from, how it is distributed, and issues associated with assuring future supplies. It provides some of the information and terminology used in the water debate, recognizing the interdisciplinary context in which the debate takes place. The issues of water demand and future water needs are addressed in the next chapter.

Hydrology, Meteorology, and Water Supply

Hydrology is the science of water and its movement through what is known as the hydrologic cycle, depicted in figure 2-1.[2] The hydrologic

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[1] See, for example, Donald A. Wilhite and Michael H. Glantz, "Understanding the Drought Phenomenon," in Donald A. Wilhite and William E. Easterling, eds., *Planning for Drought: Toward a Reduction of Societal Vulnerability* (Boulder, CO: Westview Press, 1987), 24.

[2] This discussion of the hydrologic cycle is adapted from C. W. Fetter, *Applied Hydrogeology* (Columbus, OH: Merrill Publishing, Second Edition, 1988). According to Fetter, the hydrologic cycle can be quantified by the equation: Inflow = Outflow ± Changes in Storage.

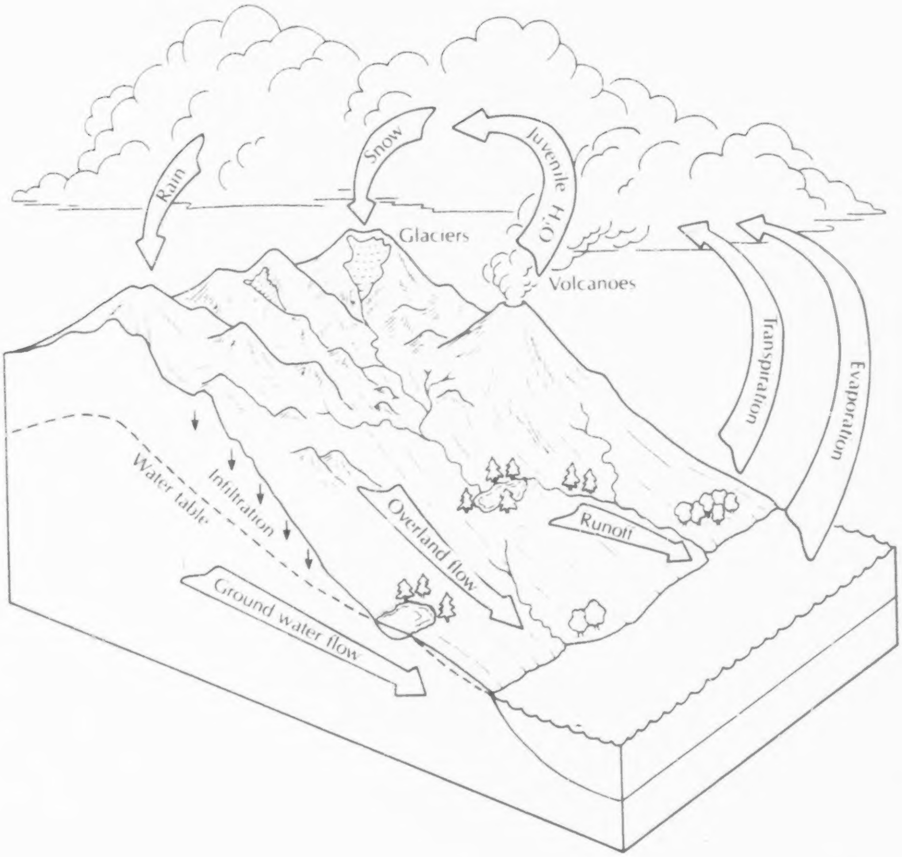
Rain
Snow
Juvenile H_2O
Glaciers
Volcanoes
Transpiration
Evaporation
Water table
Infiltration
Overland flow
Runoff
Ground water flow

Fig. 2-1. The hydrologic cycle as depicted in C. W. Fetter, *Applied Hydrogeology* (Columbus, OH: Merrill Publishing, Second Edition, 1988). Reproduced with permission.

cycle has no beginning and no end, but descriptions of it normally start with the ocean. Surface waters of the ocean evaporate (at a higher rate near the equator) and leave ocean salts behind. Vaporized water in the atmosphere condenses and then either revaporizes while still airborne or falls to the earth as precipitation. Once on land, water is transpired by plants or it moves off the land as overland flows or infiltrates the ground. Infiltrated water passes the water table, defined by the top of the saturated zone of soil and rock, and becomes groundwater. Total streamflow is known as runoff and the groundwater contribution to a stream is known as baseflow.

The hydrologic cycle is a closed system in which the same quantity of water has been in flux for eons.[3] No water disappears from the system, but its distribution is extremely uneven. The worldwide distribution of water in the hydrosphere is reported in table 2-1. As the table indicates, over 97 percent of the water in the hydrosphere is ocean water. At the other extreme, only a small fraction is found in stream channels. Even freshwater lakes constitute less than one-tenth of one percent of total water. The worldwide flux in the hydrologic cycle is reported in table 2-2. Thousands of cubic kilometers of water are in flux at any given moment--flowing, transpiring, evaporating, precipitating.

Hydrology's sister discipline is meteorology, the science of atmosphere, climate, and weather. Some scholars emphasize that the hydrologic cycle is actually an integral part of the climatic system.[4] While water systems are generally regarded as being affected by climate, water systems may affect climate, also through the hydrologic cycle.[5] The interaction of

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[3] John Bredehoeft, "Physical Limitations of Water Resources," in Ernest A. Engelbert and Ann Foley Sheuring, eds., *Water Scarcity: Impacts on Western Agriculture* (Berkeley, CA: University of California Press, 1984), 43; and Gary O. Robinette, *Water Conservation in Landscape Design and Management* (New York: Van Nostrand Reinhold Company, 1984), 8.

[4] S.I. Solomon, M. Beran, and W. Hogg, eds., *The Influence of Climate Change and Climatic Variability on the Hydrologic Regime and Water Resources* (Washington, DC: International Association of Hydrological Sciences, 1987).

[5] A. J. Askew, "Climate Change and Water Resources," in Solomon, Beran, and Hogg, eds., ibid., 421-30.

TABLE 2-1

WORLDWIDE DISTRIBUTION OF WATER IN THE HYDROSPHERE

Location	Water Volume in Liters	Percentage of Total Water
Average in stream channels	1×10^{15}	.0001
Atmosphere	13×10^{15}	.001
Vadose water, including soil moisture	67×10^{15}	.005
Saline lakes and inland areas	104×10^{15}	.008
Fresh-water lakes	125×10^{15}	.009
Ground water within depth of half a mile	$4{,}170 \times 10^{15}$	.31
Ground water, deep lying	$4{,}170 \times 10^{15}$	.31
Icecaps and glaciers	$29{,}000 \times 10^{15}$	2.15
World oceans	$1{,}320{,}000 \times 10^{15}$	97.20

Source: U.S. Geological Survey as reported in Brian J. Skinner, *Earth Resources* (Englewood Cliffs, NJ: Prentice-Hall, 1986), 155.

TABLE 2-2

WORLDWIDE FLUX OF WATER IN THE HYDROLOGIC CYCLE

Factor	Amount per year in cubic kilometers
Deep ocean/surface ocean mixing	710,000
Evaporation from ocean areas	419,060
Precipitation on ocean areas	381,410
Precipitation on land areas	106,250
Land precipitation from ocean evaporation	94,000
Evapotranspiration from land areas	68,600
Atmospheric moisture flow, land to oceans	57,000
Runoff from land to ocean	37,650
Land precipitation from land evaporation	12,000

Source: Various sources as reported in James W. Moore, *Balancing the Needs of Water Use* (New York: Springer-Verlag, 1989), 2.

climate and hydrology is the subject of increasing scientific attention, particularly in light of concerns about global warming.[6]

Runoff, or total streamflow, is a typical measure of water supply. Runoff is a function of both temperature and precipitation, as seen in table 2-3. The relationship is well established and highly intuitive: runoff is greatest when rainfall is high and temperatures are low, and lowest when rainfall is low and temperatures are high. Arid regions are highly sensitive to these relationships because of the greater likelihood of dryness and warmth. Knowing the meteorological patterns of a locality provides much insight into the probability that water supplies will be impaired by weather factors.

Figure 2-2 presents the path of precipitation once it has fallen to earth. Seventy percent of all precipitation is returned to the hydrologic cycle through evaporation and transpiration; the rest enters stream flows. Only 8 percent of the total amount of global precipitation is withdrawn and used by humans and only .6 percent of precipitation can be traced through stream flows to municipal water withdrawals (those made by central suppliers). The Second National Water Assessment by the U.S. Water Resources Council tracked the path of precipitation, or the "water budget," for the coterminous United States, as reported in table 2-4.[7] The Council pointed out that of the 4,200 billion gallons daily (BGD) that precipitate over the nation, 2,750 BGD is immediately evaporated from wet surfaces or transpired by vegetation. Moreover, in most years only about 47 percent of the 1,450 BGD that remain is considered available for withdrawal for human use, given existing surface storage and the extremes of annual precipitation. The table also illustrates the predominantly eastward flow of both stream waters and subsurface waters.

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[6] The Great Lakes region is getting its share of attention in this area of research. Two approaches to modeling climate and hydrology for the region were M. Sanderson and L. Wong, "Climatic Change and Great Lakes Water Levels," and Stewart J. Cohen, "Sensitivity of Water Resources in the Great Lakes Region to Changes in Temperature, Precipitation, Humidity and Wind Speed," in Solomon, Beran, and Hogg, eds., *The Influence of Climate Change*.

[7] U.S. Water Resources Council, *The Nation's Water Resources: 1975-2000, Volume 1: Summary* (Washington, DC: U.S. Water Resources Council, 1978), 12.

TABLE 2-3

TEMPERATURE, PRECIPITATION, AND RUNOFF IN ARID AREAS

Weighted Average Temperature °F (°C)	Annual Precipitation in Inches (mm)					
	7.9 (200)	11.8 (300)	15.7 (400)	19.7 (500)	23.6 (600)	27.6 (700)
	Annual Runoff in Inches *					
28.4 (-2)	2.1	3.6	6.1	9.1	13.0	17.3
32.0 (0)	1.6	2.9	4.9	7.5	10.8	15.0
35.6 (2)	1.1	2.2	3.7	6.1	8.9	13.0
39.2 (4)	.7	1.6	3.1	4.9	7.5	10.4
42.8 (6)	.4	1.0	2.4	3.9	6.1	8.7
46.4 (8)	0	.7	1.7	3.2	5.0	7.3
50.0 (10)	-	.3	1.1	2.5	4.1	6.1
53.6 (12)	-	0	.7	1.9	3.1	5.1
57.2 (14)	-	-	.4	1.3	2.6	4.1
60.8 (16)	-	-	0	.8	2.0	3.3

Source: W. B. Langbein, et al., *Annual Runoff in the United States* (Washington, DC: U.S. Geological Survey, 1949) as reported in Roger R. Revelle and Paul E. Waggoner, "Effects of a Carbon Dioxide-Induced Climatic Change on Water Supplies in the Western United States," in National Research Council, *Changing Climate* (Washington, DC: National Academy Press, 1983), 420.

* The figures are averages based on representative data from 22 drainage basins for relatively arid areas. Average monthly temperatures were weighted by monthly precipitation. Precipitation and runoff were converted from millimeters to inches (1 inch = 25.4 mm) and °Celsius were converted to °Farenheit ([1.8 x °C] + 32° = °F).

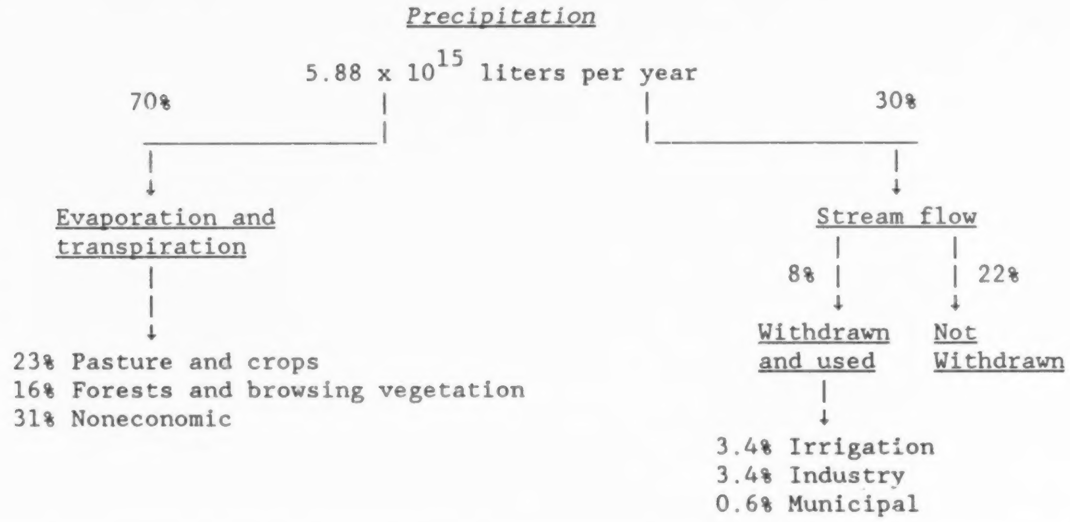
Precipitation
5.88 x 10^15 liters per year
70%
30%
Evaporation and transpiration
23% Pasture and crops
16% Forests and browsing vegetation
31% Noneconomic
Stream flow
8%
22%
Withdrawn and used
Not Withdrawn
3.4% Irrigation
3.4% Industry
0.6% Municipal

Fig. 2-2. Global path of precipitation as depicted in Brian J. Skinner, *Earth Resources* (Englewood Cliffs, NJ: Prentice-Hall, 1986), 155.

TABLE 2-4

PATH OF PRECIPITATION FOR THE COTERMINOUS UNITED STATES

In Billions of Gallons Daily (BGD)

Atmospheric moisture	40,000			
	↓			
Precipitation	4,200	→→→	Evaporation from wet surfaces or transpired from vegetation	2,750
			Streamflow to Atlantic Ocean and Gulf of Mexico	920
			Streamflow to Pacific Ocean	300
			Consumptive use	106
			Subsurface flow (east)	75
			Subsurface flow (west)	25
			Reservoir net evaporation	15
			Streamflow to Canada	6
			Streamflow to Mexico	2

Source: U.S. Water Resources Council, *The Nation's Water Resources: 1975-2000, Volume 1: Summary* (Washington, DC: U.S. Water Resources Council, 1978), 12.

The dimensions of time and space have a lot to do with how much water is available and, thus, how water issues are perceived.[8] If precipitation were evenly distributed across the globe, rainfall would amount to about 86 centimeters annually. Actually, annual precipitation varies from under 25 centimeters to more than 254 centimeters.[9] Variations in rainfall can be dramatic from year to year and even from month to month. Figure 2-3 is a map depicting typical zones of water deficiency and water surplus across the globe, based on the amount of precipitation required for well-watered vegetation. Throughout North America, both types of zones are apparent.

Water supplies on the North American continent are relatively abundant, particularly when compared with Europe and Asia on a per capita basis, as seen in table 2-5.[10] Water issues in the United States are highly regional, however, because of dramatic differences in water's availability.[11] Water withdrawals east and west of the 100th Meridian (running through Dodge City, Kansas) are roughly comparable at a little over five-hundred-thousand acre-feet daily, about 54 percent of dependable supplies. Although the West has 60 percent of the land it receives only 25 percent of the precipitation in the United States. Table 2-6 provides city-level data on precipitation, organized according to regions and states. Differences among cities can be dramatic. Average annual rainfall in New Orleans (60 inches), for example, is over eight times that for Phoenix (7 inches). Precipitation from year to year fluctuates by as much as 20 percent of the mean, and stream flows fluctuate by even larger amounts.

Human intervention in the hydrologic cycle takes many forms: producing hydroelectric power, collecting rain in a barrel for use in a garden, distributing water through a public supply system, and seeding clouds to produce rain where and when it is needed. Hydrology and water resources,

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[8] Jan Van Schifgaarde and George J. Kriz, et al., "Water: A Basic Resource," in William E. Larson, et al., eds., *Soil and Water Resources: Research Priorities for the Nation* (Madison, WI: Soil Science Society of America, Inc., 1981), 1.

[9] William W. Kellogg and Robert Schware, *Climate Change and Society* (Boulder, CO: Westview Press, 1981), 75.

[10] Per capita water demand in the United States, however, is greater than that for most nations. See chapter 3.

[11] Schifgaarde and Kriz, et al., "Water: A Basic Resource," in Larson, et al., eds., *Soil and Water Resources*, 1.

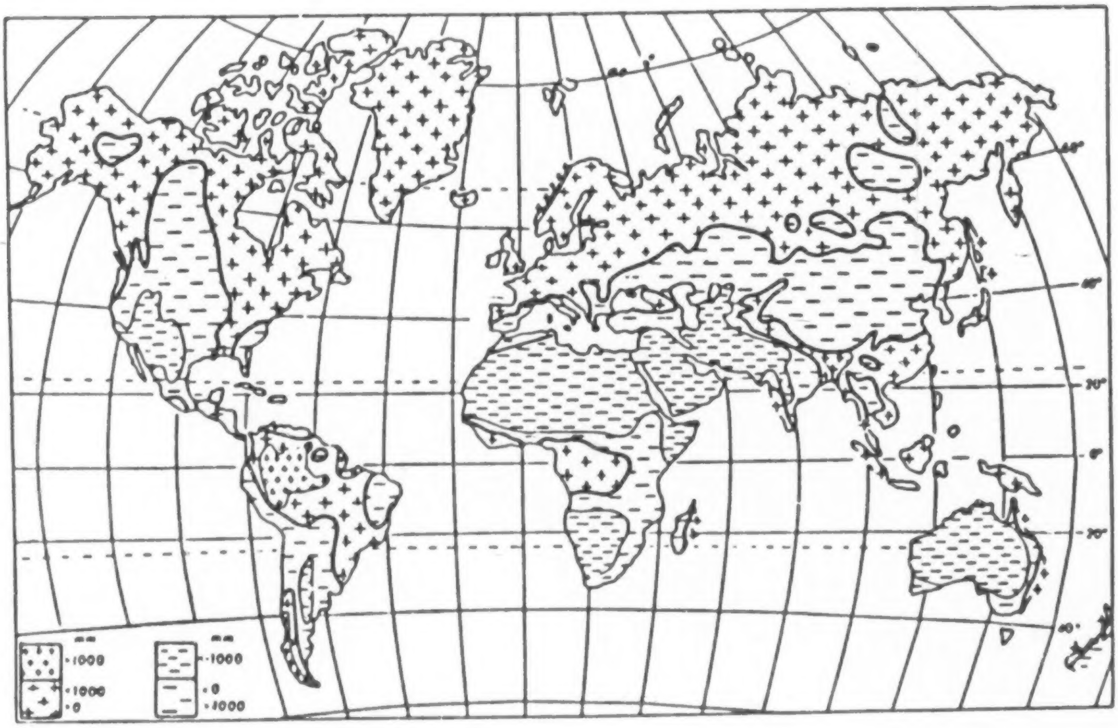
60°
30°
0°
30°
60°
mm
1000
1000
0
mm
1000
0
1000

Fig. 2-3. Global water surplus and deficiency: water-deficiency (-) and water-surplus (+) zones in the world as depicted in William W. Kellogg and Robert Schware, *Climate Change and Society* (Boulder, CO: Westview Press, 1981), 75.

TABLE 2-5

DISTRIBUTION OF WATER SUPPLIES AND POPULATION BY CONTINENT, 1980

Global Region	Supply (Runoff) Volume (a)	%	Population Millions	%	Per Capita Supply (b)
North America	6.0	14.1	252	5.6	23.8
South America	11.0	25.9	362	8.0	30.4
Europe	3.5	8.2	750	16.7	4.7
Africa (c)	4.0	9.4	470	10.4	8.5
Asia	12.5	29.4	2,641	58.7	4.7
Australia-Oceania	3.0	7.1	23	0.1	130.4
Antarctica	2.5	5.9	0	.0	--
Total	42.5	100.0	4,498	100.0	9.4

Source: A. C. Gross, "Water Quality Management Worldwide," *Environmental Management* 10 (1986), 25-39 and author's calculations.

(a) In 1000-cubic-kilometers annually.
(b) In cubic kilometers annually.
(c) Includes the Middle East.

however, are not identical. For a body of water to be a resource "it must be available, or capable of being made available, for use in sufficient quantity and quality at a location and over a period of time appropriate for an identifiable demand."[12] While having enough water may depend initially on hydrology (and being in the right place at the right time), the key to water supply is water resource development.

Humans intervene in the hydrologic cycle by means of water resource development for both instream and offstream uses. Offstream water uses (also known as water withdrawals) are made up of water diverted or withdrawn from surface or groundwater sources for use by people (as discussed in

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[12] Askew, "Climate Change and Water Resources," in Solomon, Beran, and Hogg, eds., *The Influence of Climate Change*, 423.

TABLE 2-6

PRECIPITATION IN THE UNITED STATES BY REGION, STATE, AND CITY

Census Region	State	City (a)	Normal Annual Precipitation in Inches (b)	Average Number of Days With Precipitation of .01 Inch or More (c)
Northeast	Connecticut	Hartford	44.39	127
	Maine	Portland	43.52	128
	Massachusetts	Boston	43.81	127
	New Hampshire	Concord	36.53	125
	New Jersey	Atlantic City	41.93	112
	New York	Albany	35.74	135
		Buffalo	37.52	169
		New York	44.12	121
	Pennsylvania	Philadelphia	41.42	117
		Pittsburgh	36.30	154
	Rhode Island	Providence	45.32	125
	Vermont	Burlington	33.69	154
Midwest	Illinois	Chicago	33.34	127
		Peoria	34.89	114
	Indiana	Indianapolis	39.12	125
	Iowa	Des Moines	30.83	107
	Kansas	Wichita	28.61	86
	Michigan	Detroit	30.97	134
		Sault Ste. Marie	33.48	166
	Minnesota	Duluth	29.68	135
		Minneapolis-St. Paul	26.36	115
	Missouri	Kansas City	35.16	107
		St. Louis	33.91	111
	Nebraska	Omaha	30.34	98
	North Dakota	Bismarck	15.36	97
	Ohio	Cincinnati	40.14	129
		Cleveland	35.40	156
		Columbus	36.97	137
	South Dakota	Sioux Falls	24.12	97
	Wisconsin	Milwaukee	30.94	125
South	Alabama	Mobile	64.64	122
	Arkansas	Little Rock	49.20	104
	Delaware	Wilmington	41.38	117
	D.C.	Washington	39.00	112
	Florida	Jacksonville	52.76	116
		Miami	57.55	129
	Georgia	Atlanta	48.61	115
	Kentucky	Louisville	43.56	125

TABLE 2-6--Continued

Census Region	State	City (a)	Normal Annual Precipitation in Inches (b)	Average Number of Days With Precipitation of .01 Inch or More (c)
South (cont.)	Louisiana	New Orleans	59.74	114
	Maryland	Baltimore	41.84	113
	Mississippi	Jackson	52.82	109
	North Carolina	Charlotte	43.16	111
		Raleigh	41.76	111
	Oklahoma	Oklahoma City	30.89	82
	South Carolina	Columbia	49.12	109
	Tennessee	Memphis	51.57	106
		Nashville	48.49	119
	Texas	Dallas-Fort Worth	29.46	78
		El Paso	7.82	48
		Houston	44.76	106
	Virginia	Norfolk	45.22	114
		Richmond	44.07	113
	West Virginia	Charleston	42.43	152
West	Alaska	Juneau	53.15	220
	Arizona	Phoenix	7.11	36
	California	Los Angeles	12.08	36
		Sacramento	17.10	58
		San Francisco	19.71	62
	Colorado	Denver	15.31	88
	Hawaii	Honolulu	23.47	100
	Idaho	Boise	11.71	92
	Montana	Great Falls	15.24	101
	Nevada	Reno	7.49	51
	New Mexico	Albuquerque	8.12	60
	Oregon	Portland	37.39	153
	Utah	Salt Lake City	15.31	91
	Washington	Seattle-Tacoma	38.60	157
		Spokane	16.71	114
	Wyoming	Cheyenne	13.31	98

Source: U.S. Bureau of the Census, *Statistical Abstract of the United States 1988* (Washington, DC: U.S. Department of Commerce, 1987), 202-203.

(a) All data were recorded at the airport, except for New York City, where data were recorded at city offices.

(b) Normal annual precipitation based on a standard 30-year period (1951-1980).

(c) Annual averages from period of record through 1986 except for Juneau (through 1985) and New York City (through 1983).

chapter 3). Withdrawn water is either put to consumptive or nonconsumptive uses. Water for nonconsumptive uses is released from the point of use and discharged through return flows to surface or groundwater sources. Water for consumptive uses, by contrast, is withdrawn but not returned directly to any water source, although it does return to the hydrologic cycle at some point.[13]

The amount of water available for withdrawal and use can be expressed by the following equation:[14]

$$W_t = N_t - T_t - D_t - r_t + E_t$$

For a given time period (t):

W_t = Total withdrawals for consumptive and nonconsumptive uses;

N_t = New water (liquid) from precipitation and inflow (via rivers, streams, underground flows, aqueducts, and so forth);

T_t = The sum of losses from liquid water through transpiration and evaporation other than vapor losses associated with withdrawals;

D_t = Liquid discharge away from the area through surface streams underground flows, storm drains, sewers, and the like;

r_t = The net change in the liquid water stored either on the surface or underground through natural or artificial means (such as underground aquifers or reservoirs); and

E_t = The amount of effluent withdrawals in the form of recycled water, also called nonconsumptive water use.

The concept of "safe yield" is a guiding principle in water resource development. Historically, the term was used to refer to the amount of water that could be pumped "regularly and permanently without dangerous depletion of the storage reserve."[15] C. W. Fetter provides a composite definition of safe yield that has contemporary relevance because it considers additional constraints. Accordingly, safe yield can be defined as "the amount of naturally occurring ground water that can be withdrawn from an aquifer on a sustained basis, economically and legally, without impairing the native groundwater quality or creating an undesirable effect such as environmental damage."[16]

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[13] Wayne B. Solley, Charles F. Merk, and Robert R. Pierce, *Estimated Use of Water in the United States* (Washington, DC: United States Geological Survey Circular 1004, 1988).

[14] Richard A. Berk, et al., *Water Shortage: Lessons in Conservation from the Great California Drought, 1976-77* (Cambridge, MA: Abt Books, 1981), 10.

[15] Fetter, *Applied Hydrogeology*, 450.

Thus, from the standpoint of the hydrologic system, the availability of water for withdrawal is not strictly a function of precipitation. Rates of flow, storage levels, and the return of unconsumed water to the system also determine whether water supplies are abundant or scarce and the amount of safe yield. Whether humid or arid, water-rich or water-poor, every locality is accustomed to an average water condition. Water supplies anywhere, however, may at some point in time become impaired by natural or artificial causes.

Water Supply Impairment

Water supplies can be impaired for a variety of reasons. First, however, it is useful to distinguish between impairments that have an effect on quantity and those that have an effect on quality. This makes it possible to distinguish between shortages of water in general and shortages of water of acceptable quality. Second, it is useful to distinguish between natural causes and artificial causes of water supply impairments.

A typology of impairments along the cause and impact dimensions is presented in table 2-7. Each cell of the matrix represents some of the examples of water supply impairments. Drought, for instance, is a natural cause of shortages in water quantity. By contrast, water quantity can be impaired by lack of planning or an inadequate infrastructure for water delivery. Water quality can be impaired by natural causes--as in the case of salinity--or by artificial causes--as in the case of pollution. Impairments in quality such as pollution, of course, can lead to impairments in the quantity of water supplied.

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[16] Ibid.

TABLE 2-7

A TYPOLOGY OF SELECTED WATER SUPPLY IMPAIRMENTS

		IMPACT	
		Quantity	Quality
CAUSE	Natural	arid climate inaccessibility natural disasters (e.g., drought)	salinity acidity natural disasters (e.g., volcanoes)
	Artificial	overconsumption cost and cost recovery inadequate forecasting inadequate infrastructure inadequate technology legal barriers (e.g., water rights)	inadequate treatment pollution improper waste disposal manmade disasters (e.g., spills)

Source: Authors' construct.

Each type of water supply impairment suggests certain solutions to water supply problems, as illustrated in table 2-8. Often, one solution addresses more that one type of problem. A simple solution may be for societies to adapt to new conditions. Another may be to find alternative water supplies. Planning can play a role in addressing virtually every type of water supply impairment, with a slightly different emphasis depending on the type of impairment. For artificial causes, institutional solutions play a significant role. These include removing institutional barriers, improving regulation, integrating planning efforts, and controlling pollution. Designing appropriate solutions to water supply problems depends on targeting the cause of the problem and mitigating its effect on quantity, quality, or both.[17]

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[17] Later chapters in this report deal with water supply solutions, particularly drought mitigation (chapter 6) and conservation (chapter 7).

TABLE 2-8

A TYPOLOGY OF SELECTED WATER SUPPLY SOLUTIONS

		IMPACT	
		Quantity	Quality
CAUSE	Natural	adaptation alternative supplies emergency planning (e.g., drought management) improved disaster response	adaptation technological solutions reduced standards emergency planning improved disaster response
	Artificial	improved regulation removal of barriers long-term planning improved technology	improved regulation technological solutions pollution control integrated planning improved disaster response

Source: Authors' construct.

Water Supply Assessments

Assessments of the nation's water resources have evoked considerable disagreement over the accuracy of supply projections. As mentioned earlier, not all studies conclude that a water crisis is imminent. There is somewhat more consensus over the critical problems facing the nation's water supplies, all of which intensify the competition for water. Projections of future supplies are intrinsically related to assessments of problem areas.

The nation's water resources regions are defined according to the major river basin boundaries, illustrated in figure 2-4.[18] Especially water-rich

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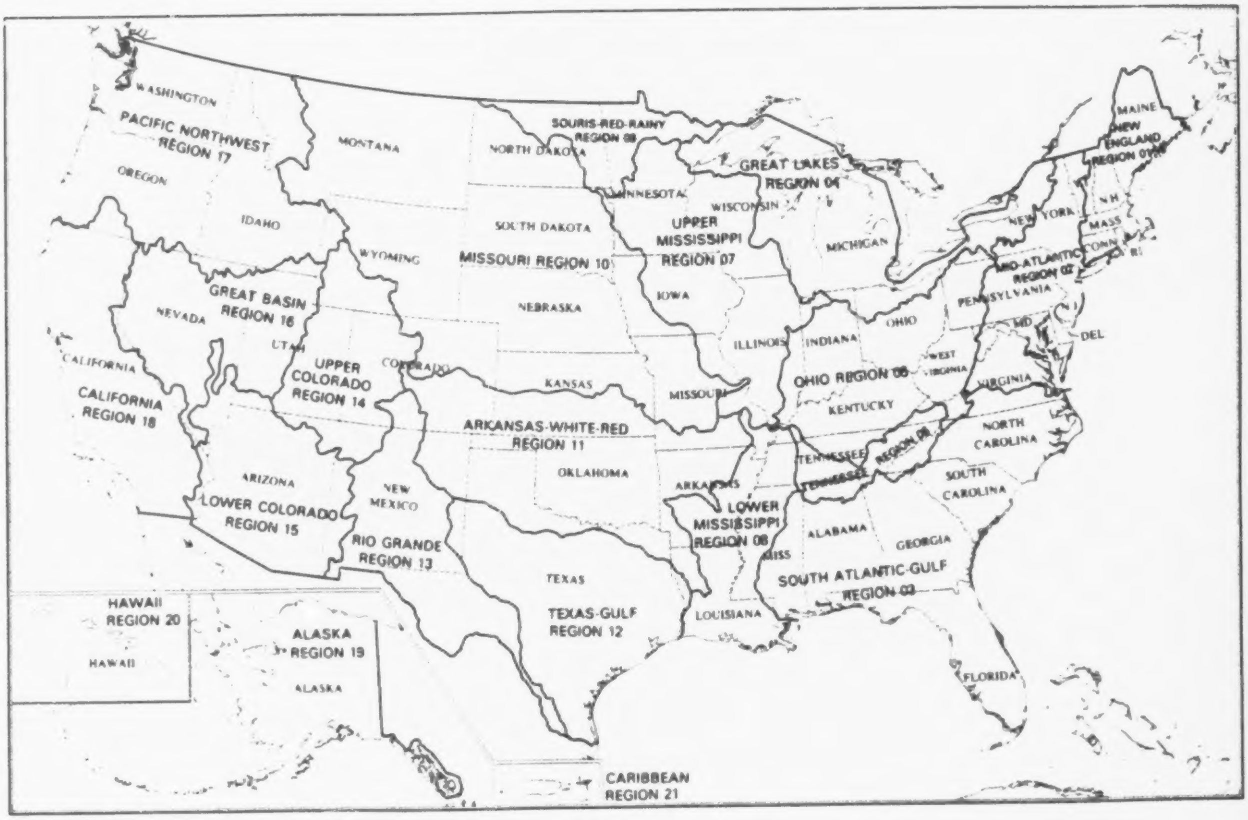
[18] John L. Moore, et al., *The Nation's Water Supply: An Overview of Conditions and Prospects* (Washington, DC: Congressional Research Service, Library of Congress, 1986).



WASHINGTON
PACIFIC NORTHWEST REGION 17
OREGON
IDAHO
MONTANA
SOURIS-RED-RAINY REGION 09
NORTH DAKOTA
MINNESOTA
GREAT LAKES REGION 04
WISCONSIN
UPPER MISSISSIPPI REGION 07
MICHIGAN
SOUTH DAKOTA
WYOMING
MISSOURI REGION 10
GREAT BASIN REGION 16
NEVADA
UTAH
IOWA
NEBRASKA
CALIFORNIA
CALIFORNIA REGION 18
UPPER COLORADO REGION 14
COLORADO
KANSAS
ILLINOIS
INDIANA
OHIO
MISSOURI
OHIO REGION 05
WEST VIRGINIA
KENTUCKY
ARKANSAS-WHITE-RED REGION 11
ARIZONA
LOWER COLORADO REGION 15
NEW MEXICO
OKLAHOMA
ARKANSAS
TENNESSEE
TENNESSEE REGION 06
LOWER MISSISSIPPI REGION 08
RIO GRANDE REGION 13
TEXAS
TEXAS-GULF REGION 12
LOUISIANA
MISS
ALABAMA
GEORGIA
SOUTH ATLANTIC-GULF REGION 03
SOUTH CAROLINA
NORTH CAROLINA
VIRGINIA
MD
DEL
PENNSYLVANIA
MID-ATLANTIC REGION 02
NEW YORK
CONN
MASS
RI
NH
MAINE
NEW ENGLAND REGION 01
FLORIDA
HAWAII REGION 20
HAWAII
ALASKA REGION 19
ALASKA
CARIBBEAN REGION 21

Fig. 2-4. Water resources regions of the United States as depicted in Wayne B. Solley, Charles F. Merk, and Robert R. Pierce, *Estimated Use of Water in the United States in 1985* (Washington, DC: U.S. Geological Survey, 1988), inside cover.

regions are the Mississippi River Valley, the Pacific Northwest, and the South Atlantic-Gulf. In fact, aggregate statistics do not support the idea of a water crisis for most parts of the country. As indicated in table 2-9, based on data for 1980, thirteen of the nation's twenty-one water resources regions consume less than 10 percent of their renewable water supplies. The remaining regions, however, consume much more. Most notable is the Colorado River Basin, where use exceeds supplies and the difference must be made up by drawing down groundwater resources.[19] Depending on water demand, other regions could experience comparable water shortages. When consumption takes a large share of renewable supplies, areas become more vulnerable to drought conditions and other supply impairments.

The key water supply issues for each water resource region were identified in a study by the Congressional Research Service, as reported in table 2-10. This assessment distinguishes between water quantity, water quality, and institutional issues affecting each of the nation's major river basins. Water quantity problems include heavy withdrawals in New England from both surface and ground sources, groundwater overdrafts in the Texas Gulf, and conflicts between instream and offstream uses throughout the Western regions. Water quality problems include heavy chemical and biological loading of surface waters in the Upper Mississippi Valley and high salinity of surface waters in the Great Basin caused by irrigation runoff. Equally vexing in some regions are institutional issues, such as conflicts over water rights (Indian v. state v. federal), which occur with frequency in the West. Another example is the conflict among interest groups over lake-level regulation and use of the Great Lakes.

According to the now-dormant U.S. Water Resources Council, in its second annual assessment, the following ten categories encompass the nation's major water resource problems:[20]

- Inadequate surface-water supply
- Overdraft of groundwater
- Pollution of surface water

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[19] Ibid., 21.

[20] U.S. Water Resources Council, *The Nation's Water Resources*, 21.

TABLE 2-9

SIMPLE WATER SUPPLY BUDGETS BY WATER RESOURCES REGION, 1980

Water Resources Region	Billions of Gallons Daily: Stream Outflow	Consumptive Use	Renewable Supply (a)	Consumptive Use/ Renewable Supply (%)
New England	77.8	0.6	78.4	1%
Mid-Atlantic	78.9	1.8	80.7	2
South Atlantic-Gulf	227.9	5.6	233.5	2
Great Lakes	72.7	1.6	74.3	2
Ohio (b)	137.5	2.1	139.6	2
Tennessee	40.8	0.4	41.2	1
Upper Mississippi (c)	75.1	2.1	77.2	3
Mississippi (d)	428.3	42.3	464.8	9
Souris-Red-Rainy	6.0	0.5	6.5	8
Missouri	45.8	19.3	62.9	31
Arkansas-White-Red	61.3	11.0	68.7	16
Texas-Gulf	27.9	8.3	33.1	25
Rio Grande	2.2	3.2	5.4	59
Upper Colorado	9.9	4.0	13.9	29
Colorado (d)	1.6	10.8	10.3	105
Great Basin	5.9	4.1	10.0	41
Pacific Northwest	263.6	12.6	276.2	5
California	50.5	25.5	74.6	34
Alaska	(e)	0.4	975.5	0
Hawaii	(e)	0.7	7.4	9
Caribbean	(e)	0.3	5.1	6

Source: U.S. Geological Survey (1983) as reported in John L. Moore, et al., *The Nation's Water Supply: An Overview of Conditions and Prospects* (Washington, DC: Congressional Research Service, Library of Congress, 1986), 10 and 22.

(a) Includes replenished groundwater and stream flow.
(b) Exclusive of Tennessee region.
(c) Exclusive of Missouri region.
(d) Entire basin.
(e) Not reported.

- Pollution of groundwater
- Quality of drinking water
- Flooding
- Erosion and sedimentation
- Dredging and disposal of dredged materials
- Wet-soils drainage and wetlands
- Degradation of bay, estuary, and coastal water

For each problem area, the Council provides a map indicating the areas of the country where the problem is particularly acute. Overlaying all ten maps would produce a composite picture in which virtually no state escapes having at least one of these major water resource problems. In addition, the Council's 1980 evaluation included assessments of two institutional problems: intergovernmental cooperation and planning and evaluation improvements. More and more, assessments of water supplies include institutional issues, or artificial causes of water resource problems. Many of these institutional issues may be rectified with improvements in conflict management, planning, and government regulation.

Forecasting Water Supply

Predicting water supplies is no easier than predicting the weather, which of course plays an integral role in determining water availability in many areas. Like any type of forecasting, uncertainty grows with the length of the forecast period and continual adjustments may be necessary. Even though the hydrologic cycle is closed, meaning that expectations about supply are shaped by certain general parameters, fluctuations around mean values can be substantial. Supply forecasts can help explain these fluctuations as well as assist in planning the development of a water resource to achieve its appropriate capacity.

For supply forecasts, the variables used in most models fall into three general categories: hydrologic, topographic, and climatic.[21] Hydrologic

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[21] See J. J. Boland, et al., *Forecasting Municipal and Industrial Water Use: A Handbook of Methods* (Fort Belvoir, VA: Institute for Water Resources, U.S. Army Corps of Engineers, 1983); B. Dzielielewski, D. D. Baumann, and J. J. Boland, *Prototypical Application of a Drought Management Optimization Procedure to an Urban Water Supply System* (Fort Belvoir, VA: Institute for Water Resources, U.S. Army Corps of Engineers, 1983); and David W. Prasifka, *Current Trends in Water Supply Planning* (New York: Van Nostrand Reinhold Co., 1988).

TABLE 2-10

MAJOR WATER SUPPLY PROBLEMS BY WATER RESOURCES REGION, 1980

Water Resources Region	Water Quantity	Water Quality	Institutional
New England	Heavy withdrawals surface and ground	Municipal/industrial pollution	
Middle Atlantic		Pollution; salinity in estuaries	
South Atlantic-Gulf	Shortages of fresh surface water in Florida and cities		
Great Lakes		Industrial, municipal, and agricultural pollution	Lake level regulation and competing interest groups
Ohio		Pollution from industrial waste and acid mines	
Tennessee		Point source pollution; low dissolved oxygen from hydroelectric discharge	
Upper Mississippi		Heavy chemical and biological loading of surface waters	Lack of comprehensive management strategy
Lower Mississippi		Industrial pollution and salinity	
Souris-Red-Rainy	Low water table because of agricultural and urban consumption	Intense recreational use, poor sewage treatment, and cropland runoff	
Missouri	Instream/offstream uses conflict		Water rights (Indian v. state v. federal)
Arkansas-White-Red	Groundwater depletion; heavy use	High salinity of surface water	
Texas Gulf	Groundwater overdrafts; declining water tables	Salinity; pollution	

TABLE 2-10--Continued

Water Resources Region	Water Quantity	Water Quality	Institutional
Rio Grande	Instream/offstream uses conflict; overappropriation; high phraetophyte consumption	High salinity of surface waters, hypersaline inflow to estuary	
Upper Colorado	Instream/offstream uses conflict; water storage and delivery systems	High salinity of surface water and groundwater; pollution from mining	Water rights (Indian v. state v. federal)
Lower Colorado	Instream/offstream uses conflict; declining water table	High salinity of surface water and groundwater; pollution from mining	Water rights (Indian v. state v. federal)
Great Basin	Shortages during critical flow; high diversion requirements	High salinity of surface waters from irrigation runoff	Water rights
Pacific North-West	Instream/offstream uses conflict (irrigation)		
California	Distribution problems; excessive groundwater uses; drainage; salt balance		
Alaska	- - - - - - - - - No major water problems as yet - - - - - - - - -		
Hawaii			Water rights
Caribbean	Periodic water shortages; distribution problems; groundwater use limited; storage		

Source: Adapted from Warren Viessman, Jr. and Christine DeMoncada, *Water Use Trends to the Year 2000* (Washington, DC: Congressional Research Service, Library of Congress, 1980), 271.

indicators include reservoir rating curves, drainage area, streamflow, raw water quality, and the hydrologic characteristics of alternative sources (including yield estimates, water quality, and minimum flow requirements). Topographic indicators include regional maps, soil moisture conditions, and the extent to which drought-tolerant landscaping is used. Climatic indicators include air temperature, precipitation (rainfall and snowfall), and moisture deficit.

The U.S. Army Corps of Engineers' Institute for Water Resources has published a series of reports on water supply forecasting and planning. One study summarizes several methods of water supply forecasting, as reported in table 2-11. Each method has different data requirements, depending on its focus, and advantages and disadvantages depending on its application. Most are highly technical in nature and limited in the sense that they focus strictly on the hydrologic supply side. However, they also serve an important role in integrated approaches that combine expectations about supply with expectations about demand for planning purposes.

Hydrology and Global Warming

Hydrology and meteorology are the center of attention in most studies of global warming, also known as "the greenhouse effect." Some analysts even link the recurrence of drought to global warming. *The Global 2000 Report to the President* utilized three climate scenarios between 1975 and 2000 developed by a diverse group of climatological experts whose opinions were weighted according to their expertise.[22] The "no change" case assumes temperatures and precipitation similar to the years 1941-1970 (with less temperature variability than the past one-hundred to two-hundred years), less severe drought in the Sahel, and less monsoon failure in India. The "warming" scenario assumes a 1° C increase in global temperatures, with only slight warming in the tropics, an increase in annual precipitation by 5 to 10 percent, and less variability in precipitation. The "cooling" scenario

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[22] Gerald O. Barney, *The Global 2000 Report to the President of the U.S.: Entering the 21st Century* (New York: Pergamon Press, 1980), 78-79.

TABLE 2-11

SELECTED WATER SUPPLY FORECASTING METHODS

Method	Type of Forecast	Data Requirements
Basin Climatic Index (BDI) Method	Expected total for 12 months' runoff, with 10 25, and 50 percent probability of occurrence.	Drainage basin or regional data: long-term average BCIs and runoff, monthly precipitation and temperature.
Position Analysis	Percent probability of complete exhaustion of of the reservoir storage during drought.	Monthly inflow, withdrawals and evaporation for a reservoir plus current reservoir storage.
U.S. Geological Survey Technique	Percent probability of a dry reservoir based on representative trace of inflows.	Historical and filled-in stream-flow data.
National Weather Service River Forecasting Systems (NWS-RFS)	Simulated stream flows; total volume of flow; maximum, minimum, and average mean daily flow.	Hydrological parameters and initial conditions of a watershed, including moisture storage contents, snowpack water-equivalents, future time-series of mean areal precipitation, and temperature (at least 10-20 years of record).
Snow Accumulation and Ablation Model	Snow cover outflow plus rain that fell on bare ground.	Air temperature, snow pack water equivalents, other snow-cover variables.
Sacramento Soil Moisture Accounting Model	Five components of water flow: direct runoff; surface runoff; lateral drainage interflow; supplementary baseflow; and primary baseflow.	Same as for the NWS-RFS model (above).

TABLE 2-11--Continued

Method	Type of Forecast	Data Requirements
Sensitivity Approach (for the NWS-RFS rainfall-runoff procedures)	Same as for the NWS-RFS model (above).	Typical trace of 6-hour-interval rain data, current soil moisture, variance of rainfall input.
Stochastic Conceptual Hydrologic Model (based on NWS-RFS)	Stream-flow forecasts 6, 12, 18, 24, 30, and 36 hours in advance.	Rainfall data in 6-hour time steps and incoming real-time discharge.

Source: Benedykt Dziegielewski, Duane D. Baumann, and John J. Boland, *Evaluation of Drought Management Measures for Municipal and Industrial Water Supply* (Fort Belvoir, VA: Institute for Water Resources, U.S. Army Corps of Engineers, 1983), 26-27.

assumes a 0.5° C decrease in global temperatures, with only slight cooling in the tropics, a decrease in annual precipitation, and more variability in precipitation.

Interestingly, the report hypothesizes that the probability of drought in the continental United States will increase in both the warming *and* the cooling scenarios. Thus, some experts see domestic drought in the future, regardless of disagreements about overall warming or cooling trends.

The potential for a greenhouse effect caused by a buildup of carbon dioxide as well as chlorofluorocarbons, methane, and nitrous oxide, is a cause for continued concern and debate in the scientific community. In testimony before the Senate Subcommittee on Science, Technology, and Space of the Committee on Commerce, Science, and Transportation, J. D. Mahlman, a laboratory director with the National Oceanic and Atmospheric Administration

(NOAA), submitted the following predictions based on his model of climate changes due to greenhouse gases, along with their probability of occurrence:[23]

- Large stratospheric cooling (virtually certain)
- Global-mean surface warming (very probable)
- Global-mean precipitation increase (very probable)
- Northern polar winter surface warming (very probable)
- Reduction of sea ice (very probable)
- Northern high latitude precipitation increase (probable)
- Summer continental dryness/warming (probable)
- Rise in global mean sea level (probable)
- Regional vegetation changes (uncertain)
- Tropical storm increases (uncertain)

Average global warming over the long-run is calculated to be between 1.5° to 4.5° C. While the model predicts an increase in global precipitation on average, local regions of the world may experience decreases in precipitation. Another probable effect is increased dryness and warming in interior continental regions, indicated by lower soil moisture caused by earlier ends to snow melt and spring rains.

James E. Hansen of the National Aeronautics and Space Administration's Goddard Institute for Space Studies also testified before the Senate in the spring of 1989.[24] His analysis provides specific projections of extreme weather conditions, both wet and dry, based on anticipated greenhouse effects.[25] The model on which the testimony was based predicts more frequent and more intense drought conditions because of higher surface air temperatures, which, in turn, increase the rate of evaporation. Because droughts are interspersed spatially and temporally, however, more detailed analysis becomes difficult. The authors also "emphasize that, even as droughts intensify with a growing greenhouse effect, all of the droughts continued to be 'natural,' in the sense that their location and timing can be related to antecedent land, atmosphere and ocean conditions."[26] Hansen and his colleagues conclude their Senate testimony by saying that the results of current climate studies indicate "it is appropriate to encourage those steps which would reduce the rate of growth of the greenhouse gases and which would make good policy independent of the climate change issue."[27]

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[23] J. D. Mahlman, "Testimony of J. D. Mahlman Before the Subcommittee on Science, Technology, and Space of the Committee on Commerce, Science, and Transportation, United States Senate" (May 8, 1989).

[24] James E. Hansen, "Statement of James E. Hansen Presented to the Subcommittee on Science, Technology, and Space of the Committee on Commerce, Science, and Transportation, United States Senate" (May 8, 1989).

[25] The testimony incorporates J. Hansen, et al., "Regional Greenhouse Climate Effects," in *Proceedings of the Second North American Conference on Preparing for Climate Change, December 6-8 1988* (Washington, DC: Climate Institute, 1989).

The policy implications of global warming are extensive, including potentially serious consequences for water resource planning and development. As reported in table 2-12, Roger R. Revelle and Paul E. Waggoner predict that a 2° C temperature increase and a 10 percent reduction in precipitation would result in a 53 percent reduction in water supply for the Western water resources regions, and that at present rates of use, supply would actually fall short of demand in the year 2000. The authors note that major water resource systems take thirty to fifty years to be planned and constructed, and that in the past, "these activities have been based on the explicit assumption of unchanging climate."[28] The potential effects of a carbon-dioxide-induced climatic change over the next five to ten decades would "warrant careful consideration by planners of ways to create more robust and resilient water-resource systems that will, insofar as possible, mitigate these effects."[29]

According to many scientists, however, statistical analyses of global temperatures and precipitation are not yet sufficient either to support or refute the greenhouse effect. One recent study found no statistically significant evidence of an overall increase in annual temperature or change in annual precipitation for the contiguous United States for the period 1895 to 1987.[30] Another recent and widely publicized study concludes that, "Current forecasts of the artificial greenhouse effect do not appear to be

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[26] Ibid., 2.

[27] Ibid., 17.

[28] Roger R. Revelle and Paul E. Waggoner, "Effects of a Carbon Dioxide-Induced Climatic Change on Water Supplies in the Western United States," in National Research Council, *Changing Climate* (Washington, DC: National Academy Press, 1983), 431.

[29] Ibid.

[30] Kirby Hanson, George A. Maul, and Thomas R. Karl, "Are Atmospheric 'Greenhouse' Effects Apparent in the Climatic Record of the Contiguous U.S. (1895-1987)?," *Geophysical Research Letters* 16, no. 1 (January 1989): 49-52.

TABLE 2-12

WATER SUPPLIES AND CLIMATIC CHANGE IN THE WESTERN UNITED STATES

Western Water Resources Region	Average Annual Supply in Billion Cubic Meters: Present Climate	Average Annual Supply in Billion Cubic Meters: Altered Climate (a)	Percentage Change	Ratio of Demand in Year 2000 to Altered Supply
Missouri	85.0	30.7	-64%	1.2
Arkansas-White-Red	93.5	43.2	-54	0.4
Texas Gulf	49.2	24.7	-50	0.7
Rio Grande	7.4	1.8	-76	3.7
Upper Colorado	16.4	9.9	-40	1.7
Lower Colorado	11.5	5.0	-57	2.7
California	101.8	57.1	-44	0.7
All regions	359.9 (b)	165.3	-53%	0.9

Source: Roger R. Revelle and Paul E. Waggoner, "Effects of a Carbon Dioxide-Induced Climatic Change on Water Supplies in the Western United States," in National Research Council, *Changing Climate* (Washington, DC: National Academy Press, 1983) as reported in Sandra Postel, "Stabilizing Chemical Cycles," in Lester R. Brown, et al., *State of the World 1987* (New York: W. W. Norton and Co., 1987), 165.

(a) Assumes a 2° C temperature increase and a 10 percent reduction in precipitation.
(b) Does not equal sum of column because a portion of Lower Colorado flow is derived from Upper Colorado.

sufficiently accurate to be used as a basis for sound national policy decision."[31]

The jury is still out on all the implications of the greenhouse issue; a verdict cannot be expected any time soon. This does not mean that no policy attention should be given to the issue. And even if the drought of 1988 or any other drought is not seen as part of the greenhouse effect (and even if one does not subscribe to the greenhouse effect at all), some prominent members of the scientific community predict that in the long run, drought conditions may occur with greater frequency and/or intensity. In any case, policies that address the causes of climatic change and policies that seek to mitigate its effects are both likely to remain high on the national policy agenda.

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[31] George C. Marshall Institute, *Scientific Perspectives on the Greenhouse Problem* (Washington, DC: George C. Marshall Institute, 1989), 33.

Future Water Supply Issues

As discussed in chapter 1, the terms scarcity and crisis are closely associated with the issue of water supply. Despite the closed nature of the hydrologic cycle, there is a growing sense that the earth is running out of water. This is not true, of course. For reasons of nature and mankind, however, levels of supply and demand in some areas are in closer proximity and the limits to readily available supplies are increasingly apparent, particularly in certain regions. Having exploited the easily developed water resources, new supplies are more difficult and more expensive to come by. Competition among water uses also is on the rise.[32]

Crisis management can lead to water supply solutions that may not be justifiable in wise-use terms. Some of the more extreme proposals for intervening in the hydrologic cycle on a grand scale to assure future water supplies were compiled by John R. Schaeffer and Leonard A. Stevens: [33]

- Towing icebergs from Antarctica to the California coast, where water from the melting ice would be pumped ashore for human consumption;
- Using nuclear-powered pumps to shuttle water by pipeline across North America from water-rich to water-short areas--such as borrowing from the Columbia River to augment the Colorado, or contributing to irrigation on the Great Plains with water from the Great Lakes;

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[32] See chapter 3.

[33] John R. Schaeffer and Leonard A. Stevens, *Future Water: An Exciting Solution to America's Most Serious Resource Crisis* (New York: William Morrow and Company, 1983), 15.

- Smearing stretches of the Arctic with carbon black, causing the ice cap to melt in the sun, and then piping the water to the United States or producing the same water by using massive nuclear-bomb-fired steam chambers carved in the ice;
- Desalting the oceans to provide the world's most expensive potable water;
- Extending pipelines into the far north to transport iceballs that would be melted by friction with the pipes on their southward journey, so as to arrive as freshwater at arid destinations.

Proposals advocating the construction of an elaborate interconnected continental canal system for North America are generally of the same caliber in terms of expense, environmental impact, and institutional complexity.[34]

Some of these proposals may be *technically* feasible and some (such as desalinization) may have limited applications today, but generally are appropriate on a much smaller scale and often under special circumstances. Rather than making dramatic attempts to intervene in the hydrologic cycle, a more reasonable approach may be to make improvements in how water resources are currently developed and utilized. This suggests that future supply issues will be greatly influence by the wise-use-of-water theme.

Efficiency improvements and planning are central to this theme. Technological innovations in water treatment and water delivery may play a role. More attention may be focused on the economies of water supply and alternative methods for resource development and delivery, including water markets. Large-scale projects, like those described above, may be compared to incremental additions to supply capacity. The renewability of water resources, including recycling and reuse, are likely to be key water supply issues in the coming years. There is also the possibility of adapting to changing water supply conditions, in part through demand management.

All of these issues occur in a regulatory context. Regulation and regulatory alternatives for water resource development, planning, and use are likely to be prominent on the policy agenda. Obviously, water supply solutions cannot be designed or implemented in a vacuum. Each must incorporate implications for water use. The next chapter addresses the withdrawal of water from the hydrologic system for major uses as well as projections of future water demand.

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[34] For a discussion of some of these proposals, see Harvey O. Banks, Jean O. Williams, and Joe B. Harris, "Developing New Water Supplies," in Engelbert and Scheuring, eds., *Water Scarcity*, 109-29.

CHAPTER 3

WATER DEMAND

Humans routinely intervene in the hydrologic cycle, borrowing from it to tend to their water needs. This intervention can be understood in terms of water demand. Many advocates of water conservation believe that society has failed to adequately control its water demand and that doing so would help alleviate the problem of scarcity. At higher water prices, the incentive to control demand grows.

Human life depends on water, although some human activities are more water intense than others. The competition for water resources was introduced in chapter 1. Water uses can generally be characterized as either instream or offstream uses. The principal instream uses are for recreation, fish and wildlife, navigation, and hydroelectric power generation. The principal offstream uses are for domestic and commercial purposes, agriculture, industry, and energy development. The competition for water is a competition among water users in all of these areas, both instream and offstream. However, the analysis in this report is generally confined to *offstream* uses of freshwater withdrawals and projections of future water needs.

Water Withdrawals and Consumption

As noted in the previous chapter, water supplies in the United States compare favorably to those in other parts of the world. Water use in this country, however, far exceeds that of many others as reported in table 3-1. According to Sandra Postel, annual per capita use in the United States is 7,200 liters, with the next highest level of water consumption being 4,800

TABLE 3-1

WATER USE IN SELECTED COUNTRIES

Country*	Total Use in Billion Liters	Per Capita Use in 1000 Liters	Percentage Distribution		
			Agriculture	Industrial	Municipal
United States	1,683	7.2	34	57	9
Canada	120	4.8	7	84	9
Soviet Union	967	3.6	64	30	6
Japan	306	2.6	29	61	10
Mexico	149	2.0	88	7	5
India	1,058	1.5	92	2	6
United Kingdom	78	1.4	1	85	14
Poland	46	1.3	-21	62	17
China	1,260	1.2	87	7	6
Indonesia	115	0.7	86	3	11

Source: Various sources reported in Sandra Postel, "Fresh Water Supplies and Competing Uses," in David H. Speidel, Lon C. Ruedisili, and Allen F. Agnew, eds., *Perspectives on Water: Uses and Abuses* (New York: Oxford University Press, 1988) 107.

* Data are for 1980 except for Mexico (1975) and India, Indonesia, and Japan (1977).

liters in Canada.[1] At the other end of the spectrum, per capita water use in Indonesia, at 700 liters, is one-tenth that of the United States.

In the water resources literature, water demand for offstream purposes is frequently discussed in terms of historic and projected water use. Water use in this context is defined and measured according to two different activities: withdrawal and consumption. Withdrawals come either from ground or surface water sources and are normally associated with specific categories of use. Water that is consumed is the quantity of withdrawn water "that is evaporated, transpired, incorporated into products and crops, consumed by humans or livestock, or otherwise removed from the immediate water supply."[2] Water that is not consumed is discharged from the point of use to a surface or groundwater source, and constitutes return flows. Thus withdrawals always exceed water consumption, sometimes by a large amount. Water consumption is also referred to in the literature as water depletion or the consumptive use of water.[3] In addition to freshwater use, some industrial, mining, and power production processes use saline water.

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[1] Sandra Postel, "Fresh Water Supplies and Competing Uses," in David H. Speidel, Lon C. Ruedisili, and Allen F. Agnew, eds., *Perspectives on Water: Uses and Abuses* (New York: Oxford University Press, 1988), 107.

[2] U.S. Water Resources Council, *The Nation's Water Resources 1975-2000, Volume 1: Summary* (Washington, DC: U.S. Water Resources Council, 1978), 2.

The U.S. Geological Survey analyzes in great detail the daily flow of water in the United States.[4] Figure 3-1 and table 3-2 summarize a recent analysis. The total amount of freshwater in the system is 338.3 billion gallons daily (BGD), coming from both surface water (78.3 percent) and groundwater (21.7 percent) sources. An intermediate water source is public supply. This category consists of water systems that serve at least twenty-five persons or have at least fifteen connections. About 11 percent of water in the public supply category is attributable to public uses (such as fire protection, street washing, municipal parks, and public swimming pools) and water losses in the distribution system (sometimes referred to as unaccounted-for water). The largest category of water use is agricultural (for both irrigation and livestock), followed in descending order by thermoelectric, public supply, domestic and commercial, and industrial and mining uses. Most water withdrawals (72.7 percent) can be traced to return flows, but consumptive use accounts for the rest (27.3 percent).

The Geological Survey also provides data on water demand by the nation's water resource regions.[5] Water withdrawals are particularly heavy in the California, Mid-Atlantic, and South Atlantic-Gulf regions. The Pacific Northwest and the Missouri regions also make heavy withdrawals. Water consumption, meanwhile, is greatest in the California, Pacific-Northwest, and Missouri regions. The Arkansas-White-Red, Texas-Gulf, and Lower Mississippi regions also consume large quantities of freshwater. A summary of freshwater withdrawals for categories of use by region is provided in table 3-3. Appendix A of this report provides state-level data

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[3] Wayne B. Solley, Charles F. Merk, and Robert R. Pierce, *Estimated Use of Water in the United States in 1985* (Washington, DC: U.S. Geological Survey, 1988), v.

[4] Ibid.

[5] Ibid. For a map depicting the regions, see figure 2-4 in chapter 2.

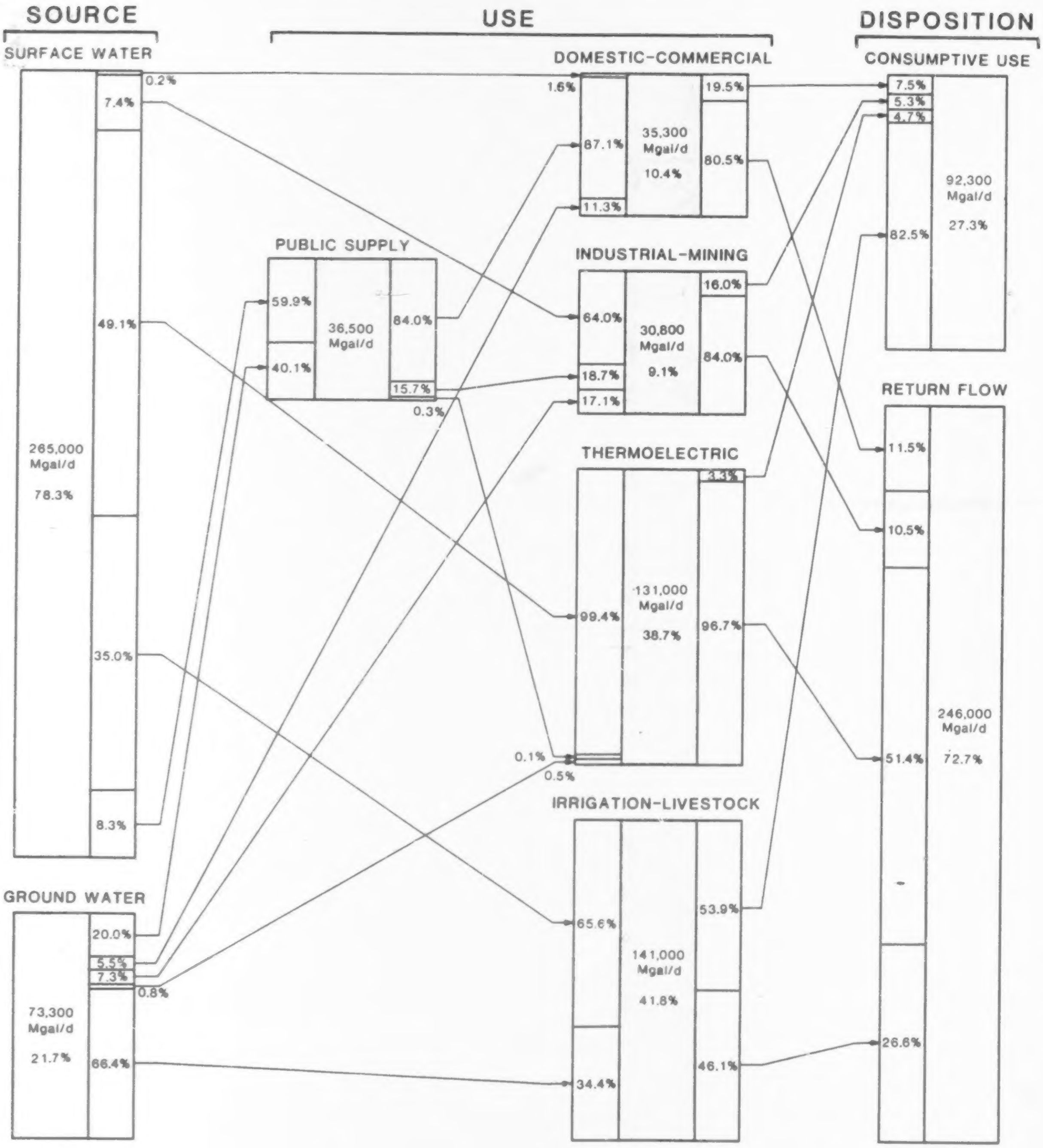
SOURCE
USE
DISPOSITION
SURFACE WATER
0.2%
7.4%
49.1%
265,000 Mgal/d
78.3%
35.0%
8.3%
GROUND WATER
20.0%
5.5%
7.3%
0.8%
73,300 Mgal/d
21.7%
66.4%
PUBLIC SUPPLY
59.9%
40.1%
36,500 Mgal/d
84.0%
15.7%
0.3%
DOMESTIC-COMMERCIAL
1.6%
87.1%
11.3%
35,300 Mgal/d
10.4%
19.5%
80.5%
INDUSTRIAL-MINING
64.0%
18.7%
17.1%
30,800 Mgal/d
9.1%
16.0%
84.0%
THERMOELECTRIC
99.4%
131,000 Mgal/d
38.7%
3.3%
96.7%
0.1%
0.5%
IRRIGATION-LIVESTOCK
65.6%
34.4%
141,000 Mgal/d
41.8%
53.9%
46.1%
CONSUMPTIVE USE
7.5%
5.3%
4.7%
82.5%
92,300 Mgal/d
27.3%
RETURN FLOW
11.5%
10.5%
51.4%
26.6%
246,000 Mgal/d
72.7%

Fig. 3-1. Sources, uses, and disposition of freshwater in the United States, 1985, as depicted in Wayne B. Solley, Charles F. Merk, and Robert R. Pierce, *Estimated Use of Water in the United States* (Washington, DC: U.S. Geological Survey, 1988), 55.

TABLE 3-2

SOURCES, USES, AND DISPOSITION OF FRESHWATER IN THE UNITED STATES, 1985

Source	Amount* (Percent)	Type of Use and Amount	Disposition	Amount* (Percent)
Surface Water	265.0 (78.3%)	→ ALL USES	→ Return Flow	246.0 (72.7%)
Ground Water	73.3 (21.7%)	→ 338.3 BGD	→ Consumptive Use	92.3 (27.3%)
Surface Water	92.5 (65.6%)	→ IRRIGATION/	→ Consumptive Use	76.0 (53.9%)
Ground Water	48.5 (34.4%)	→ LIVESTOCK	→ Return Flow	65.0 (46.1%)
		141.0 BGD		
Surface Water	130.2 (99.4%)	→ THERMO-	→ Return Flow	126.7 (96.7%)
Ground Water	.7 (0.5%)	→ ELECTRIC	→ Consumptive Use	4.3 (3.3%)
Public Supply	.1 (0.1%)	131.0 BGD		
Surface Water	21.9 (59.9%)	→ PUBLIC	→ Dom./Commercial	30.7 (84.0%)
Ground Water	14.6 (40.1%)	→ SUPPLY	→ Industrial/Mining	5.7 (15.7%)
		36.5 BGD	→ Thermoelectric	.1 (0.3%)
Public Supply	30.7 (87.1%)	→ DOMESTIC/	→ Return Flow	28.4 (80.5%)
Ground Water	4.0 (11.3%)	→ COMMERCIAL	→ Consumptive Use	6.9 (19.5%)
Surface Water	.6 (1.6%)	35.3 BGD		
Surface Water	19.7 (64.0%)	→ INDUSTRIAL/	→ Return Flow	25.9 (84.0%)
Public Supply	5.8 (18.7%)	→ MINING	→ Consumptive Use	4.9 (16.0%)
Ground Water	5.3 (17.1%)	30.8 BGD		

Source: Adapted from Wayne B. Solley, Charles F. Merk, and Robert R. Pierce, *Estimated Use of Water in the United States* (Washington, DC: U.S. Geological Survey, 1988), 55.

* In billions of gallons daily (BGD). Some figures may be affected by rounding. The totals for all uses do not reflect public supply to avoid double counting.

TABLE 3-3

WATER WITHDRAWALS BY TYPE OF USE AND WATER RESOURCES REGION, 1985

Region	Freshwater (a)						Saline
	Public Supply	Domestic and Commercial	Irrigation and Livestock	Industrial and Mining	Thermo-electric	Total (b)	
	In Millions of Gallons Daily for 1985						
New England	1,450	409	69	698	6,450	9,160	7,120
Mid-Atlantic	6,040	624	390	2,706	14,000	23,800	20,000
S.Atlantic-Gulf	4,210	800	3,907	3,727	18,900	31,600	11,900
Great Lakes	4,080	383	332	4,662	22,400	31,900	5
Ohio	2,440	440	224	3,613	24,400	31,100	18
Tennessee	469	65	69	1,776	6,810	9,190	0
U. Mississippi	1,880	523	658	1,067	12,800	16,900	20
L. Mississippi	953	91	6,702	2,309	7,010	17,100	505
Souris-Red-Rainy	64	22	88	68	38	280	0
Missouri	1,580	191	24,673	526	7,510	34,500	29
Ark.-White-Red	1,380	172	9,095	560	4,070	15,300	26
Texas-Gulf	2,460	112	5,126	949	5,020	13,700	5,140
Rio Grande	455	45	5,010	70	17	5,600	40
Upper Colorado	127	16	7,209	67	131	7,550	27
Lower Colorado	829	54	6,309	156	47	7,390	13
Great Basin	529	23	7,439	92	13	8,100	134
Pac. Northwest	1,620	306	31,890	1,199	439	35,500	37
California	5,300	196	31,001	598	480	37,600	12,300
Alaska	76	10	156	133	30	406	0
Hawaii	204	44	910	20	90	1,270	880
Caribbean	395	21	166	19	5	605	2,120
TOTAL (b)	36,500	4550	141,470	24,970	131,000	338,000	60,300

Source: Adapted from Wayne B. Solley, Charles F. Merk, and Robert R. Pierce, *Estimated Use of Water in the United States in 1985* (Washington, DC: U.S. Geological Survey, 1988), 62.

(a) The domestic and commercial category excludes publicly supplied water.
(b) Figures may not add to totals because of independent rounding.

on water withdrawals and consumption from the Geological Survey's analysis, including detailed data on public supply.

Table 3-4 reports trends in the nation's water use from 1950 to 1985 at five-year intervals. Although somewhat counterintuitive, after decades of steady growth in water use, *a 10 percent reduction in total offstream withdrawals occurred between 1980 and 1985.* Some of this reduction in withdrawals may simply have been due to improved estimating techniques, but some may be attributable to improved water-use efficiencies, more water reuse, and--for irrigation--a reduction in groundwater withdrawals because of increased availability of surface water sources.[6]

Withdrawals of water for public water supply and for rural domestic and livestock uses continued to rise between 1980 and 1985, however.[7] The increase in withdrawals for public water supply was attributed to the nearly identical increase in population (approximately 7 percent). The increase in withdrawals for rural domestic needs and livestock was attributed mainly to increases in fish farming, particularly in Arkansas, Idaho, and Mississippi.

Major Categories of Water Use

There are numerous ways of categorizing water use. This section focuses on offstream water use for domestic and commercial, agricultural, industrial, and energy development purposes.

Domestic and Commercial Water Use

Domestic and commercial water use is three-quarters domestic and one-quarter commercial. Domestic water use takes place in residential households for everyday purposes. Commercial use takes place in office buildings, hotels, restaurants, civilian and military installations, and other nonindustrial commercial enterprises. According to the Geological Survey, domestic and commercial freshwater withdrawals, including losses in the public-supply distribution system, amounted to 35.3 BGD in 1985 (table

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[6] Ibid., 68-70.

[7] Ibid.

TABLE 3-4

ESTIMATED WATER USE IN THE UNITED STATES OVER TIME, 1950-1985

	Year								Percent Change
	1950	1955	1960	1965	1970	1975	1980	1985	1980-85
	In Billions of Gallons Daily Unless Otherwise Indicated (a)								
Total offstream withdrawals	180	240	270	310	370	420	440	400	-10%
Categories of use									
Public supply	14	17	21	24	27	29	34	37	+7
Industrial									
Thermoelectric	40	72	100	130	170	200	210	190	-13
Other	37	39	38	46	47	45	45	31	-33
Rural									
Irrigation	89	110	110	120	130	140	150	140	-6
Dom./livestock	3.6	3.6	3.6	4.0	4.5	4.9	5.6	7.8	+39
Sources of water									
Ground (fresh)	34	47	50	60	68	82	83	73	-12
Ground (saline)	na	.6	.4	.5	1	1	.9	.7	-29
Surface (fresh)	140	180	190	210	250	260	290	260	-8
Surface (saline)	10	18	31	43	53	69	71	60	-16
Reclaimed sewage	na	.2	.6	.7	.5	.5	.5	.6	+22
Freshwater consumed	na	na	61	77	87	96	100	92	-9
Instream use									
Hydroelectric	1,100	1,500	2,000	2,300	2,800	3,300	3,300	3,100	-7
Population (b)	150.7	164.0	179.3	193.8	205.9	216.4	229.6	242.4	+6
Per Capita Use (c)									
Offstream	1,190	1,460	1,510	1,600	1,800	1,940	1,920	1,650	-14
Instream	7,300	9,150	11,150	11,870	13,600	15,250	14,370	12,790	-11

Source: Adapted from Wayne B. Solley, Charles F. Merk, and Robert R. Pierce, Estimated Use of Water in the United States in 1985 (Washington, DC: U.S. Geological Survey, 1988), 69 and authors' calculations.

(a) Some figures may be affected by rounding. Data for 1950-1955 are for 48 states and D.C., data for 1960-1965 are for 50 states and D.C., data for 1970 are for 50 states, D.C., and Puerto Rico, and data for 1975-1985 are for 50 states, D.C., Puerto Rico, and Virgin Islands; na = not available.

(b) In millions.

(c) In million gallons daily (mgd) per person.

3-2). Most (30.7 BGD) came from public supply but some came from self-supplied groundwater (4.0 BGD) and surface water (.6 BGD) sources. Estimates of self-supplied water are based on estimates of the population not served by public suppliers.[8] Domestic and commercial use, of course, was the biggest type of use for the 36.5 BGD public supply category. Only about 20 percent of water withdrawals for domestic and commercial purposes was consumed; the rest was returned to a water source. The Mid-Atlantic and South-Atlantic water resource regions make heavy freshwater withdrawals for domestic use, while the New England region leads the nation in withdrawals for commercial use.

Residential water use is generally divided into indoor use (including bathing, cleaning, and cooking) and outdoor use (including watering lawns and filling swimming pools). Figure 3-2 depicts typical residential water use for a family of four. Indoor use accounts for just over two-thirds of a family's total daily water use; of that, water used for toilets accounts for 41 percent of all indoor use. Water for lawns and swimming pools accounts for 91 percent of all outdoor water use. The amount of outdoor water used by a family can vary widely depending on the season, while indoor water use remains fairly stable year-round.[9] Indoor use is somewhat less discretionary than outdoor use. Demand for indoor use is considered less elastic, meaning that higher prices will not necessarily suppress consumption.

Of course, water consumption varies from one family to the next depending on such household characteristics as family size, lot size, family income, presence of a swimming pool, etc. As would be expected, total water consumption increases with the number of persons living in a household although water consumption on a per capita basis declines as the number of people in a household increases.[10] At the household level, therefore, increasing returns to scale exist in water consumption.

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[8] Ibid.

[9] Murray A. Milne, *Residential Water Conservation in the United States* (Los Angeles: School of Architecture and Urban Planning, University of California, 1978), 14.

[10] Frank H. Bollman and Melinda A. Merritt, "Community Response and Change in Residential Water Use to Conservation and Rationing Measures: A Case Study--Marin Municipal Water District," in James E. Crews and James Tang, eds., *Selected Works in Water Supply, Water Conservation and Water Quality Planning* (Fort Belvoir, VA: Institute for Water Resources, U.S. Army Corps of Engineers, 1981), 388.

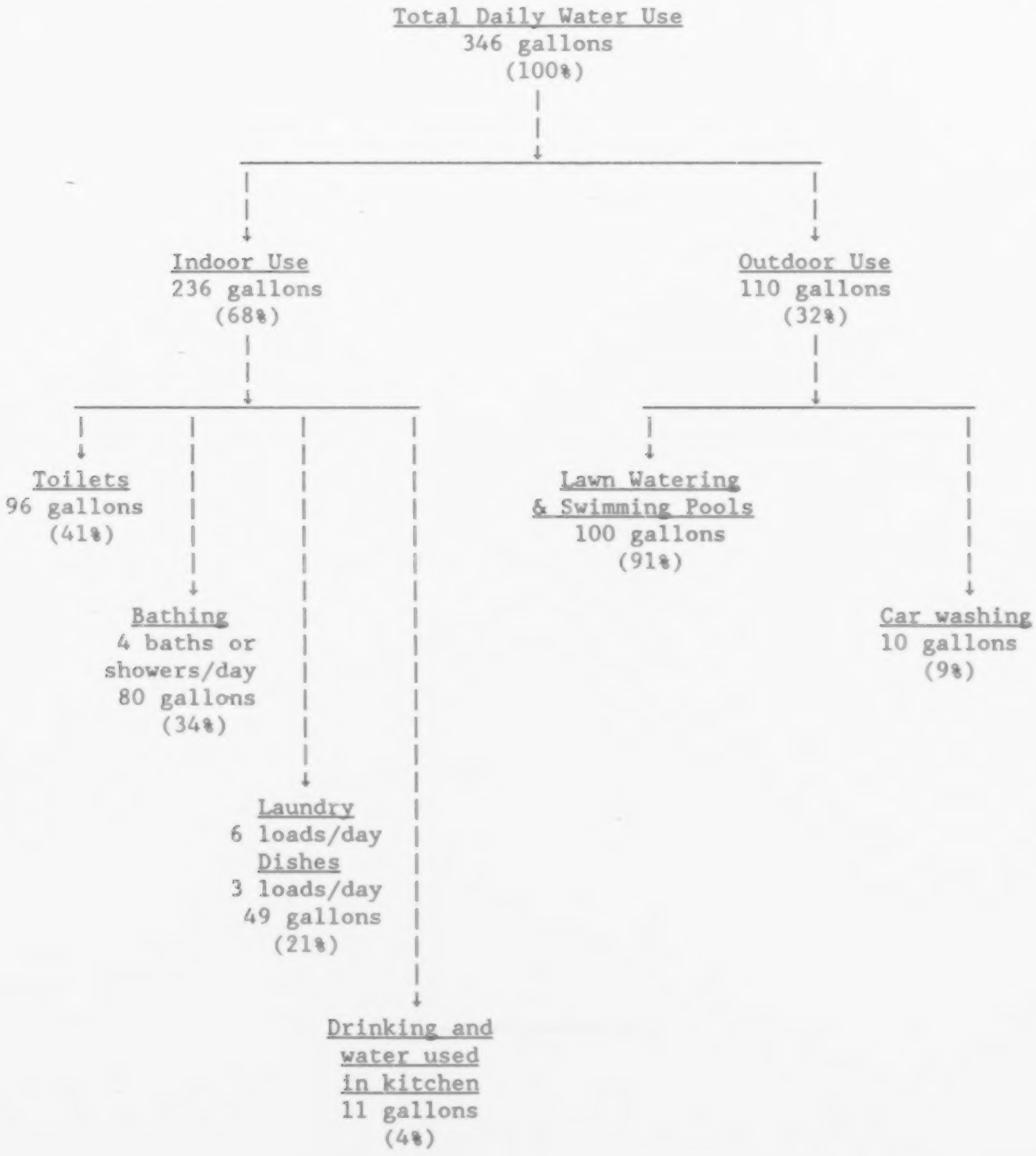
Total Daily Water Use
346 gallons
(100%)
Indoor Use
236 gallons
(68%)
Outdoor Use
110 gallons
(32%)
Toilets
96 gallons
(41%)
Bathing
4 baths or showers/day
80 gallons
(34%)
Laundry
6 loads/day
Dishes
3 loads/day
49 gallons
(21%)
Drinking and water used in kitchen
11 gallons
(4%)
Lawn Watering & Swimming Pools
100 gallons
(91%)
Car washing
10 gallons
(9%)

Fig. 3-2. Typical daily residential water use for a family of four as reported in Welford Sanders and Charles Thurow, *Water Conservation in Residential Development: Land-Use Techniques* (Chicago: American Planning Association, 1982), 6.

One water consumption study found that under "normal" consumption patterns without use restrictions, household size explained 15 percent of the variation in consumption. This amount more than doubled, to 34 percent, when strict water-use restrictions were imposed. Conversely, the importance of other household characteristics (such as those noted above) explained somewhat more variation in normal consumption and only a small amount of variation in consumption when restrictions were imposed.[11] This type of analysis suggests that researchers using end-use demand models should disaggregate such factors as household size from other potential determinants of water consumption.

Sewage treatment is another aspect of domestic water use, and especially important in terms of effects on return flows. The Geological Survey estimated that 20,631 public sewage treatment facilities released 30.8 BGD of treated water in 1985, most of which was returned to surface water sources.[12] Another 20,581 nonpublic facilities released an unknown quantity of treated water in 1985. The volume of these return flows for a given area depends largely on the size of the population and its water use.

Agricultural Water Use

Agricultural water use is the largest water use category. Water is a primary resource for every farm operation. Agricultural water use falls into two areas, irrigation and livestock, accounting for about 141 BGD of freshwater withdrawals in 1985 (table 3-2).

In 1985, about 137 BGD (154 million acre-feet) was withdrawn for irrigation, which includes golf course irrigation.[13] Most of that amount, 92.5 BGD, came from surface sources while 48.5 BGD came from ground sources. Irrigation water can be self-supplied or obtained through irrigation companies or districts. Over four-hundred million gallons daily in reclaimed sewage was also used for irrigation purposes. The loss of water in irrigation conveyance systems can be significant; 23.6 BGD estimated for 1985. Also, the consumptive use of water in agricultural operations is higher than other water use categories. For 1985, consumptive use for irrigation and livestock was estimated to be about 54 percent of withdrawals.

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[11] Ibid., 391.

[12] Solley, Merk, and Pierce, *Estimated Use of Water in the United States*.

[13] Ibid.

Because it accounts for 42 percent of all water use in the United States and a large proportion of its use is consumptive, it is no surprise that irrigation is a central water supply issue. In fact, water supply debates often focus on irrigation because of its relative magnitude when water is scarce, as in drought years. Irrigation water is also important when considering competition for water, the possibility of diversions for alternative purposes, and the potential tradeoffs involved. Historically, conflict over irrigation water has been particularly intense in the West.

The U.S. Department of Agriculture monitors the irrigation issue closely because it is part and parcel of the agricultural economics and productivity in the United States.[14] Seventeen western states account for over 85 percent of total irrigated land in the United States. Three other states--Arkansas, Florida, and Louisiana--account for another 9 percent of all irrigated land. The top five states in terms of irrigated acreage accounting for 44 percent of the irrigation farms and 55 percent of the irrigated land are: California, Nebraska, Texas, Idaho, and Colorado. Nationally, hay, corn, and wheat are the principal irrigated crops as measured by acreage. California and Texas, however, use substantial amounts of water for irrigating orchards, cotton, and sorghum.

Table 3-5 provides basic information on irrigation in the United States, including the number of farms using various irrigation methods, the sources of irrigation water, and the amount of energy required to pump irrigation water. Sprinkler and gravity systems are the most frequently used irrigation systems in the United States. Although more expensive, sprinkler systems tend to be more efficient. Drip or trickle irrigation and subirrigation are alternative methods. Most irrigation water is supplied from wells (56 percent) but off-farm sources, such as irrigation districts,

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[14] The following information on irrigation is abstracted from Rajinder S. Bajwa, William M. Crosswhite, and John E. Hostetler, *Agricultural Irrigation and Water Supply* (Washington, DC: Economic Research Service, U.S. Department of Agriculture, 1987).

TABLE 3-5

IRRIGATION METHODS AND WATER USE

Method or Source	Number of Farms	Number of Acres	Acre-feet of water per acre
Method of Irrigation			
All sprinkler systems	104,641	16,877,412	1.3
All gravity systems	126,827	27,457,244	2.0
Drip or trickle	11,651	837,624	1.9
Subirrigation	2,905	623,013	3.8
Sources of Irrigation Water			
Wells	100,703	24,286,826	1.4
Off-farm water suppliers	98,672	15,647,770	2.3
On-farm surface sources	35,982	5,886,832	1.8
On-Farm Energy Expenses for Pumping			
Electricity	96,324	18,106,589	35
Natural gas	15,519	5,800,547	34
LP gas, propane, butane	12,668	1,804,629	22
Diesel fuel	30,339	5,193,599	24
Gasoline and gasohol	6,057	162,325	23
Total energy expenses	135,319	31,067,689	32

Source: Rajinder S. Bajwa, William M. Crosswhite, and John E. Hostetler, *Agricultural Irrigation and Water Supply* (Washington, DC: Economic Research Service, U.S. Department of Agriculture, 1987), 6. Data are for 1984.

account for 32 percent of supplies. Off-farm supplies are relied upon more heavily in the western states. Irrigated farms tend to require more capital and labor than nonirrigated farms, but they are also more productive. They also incur significant energy expenses, amounting to more than three times those for nonirrigated farms. Costs vary with the type of fuel used, with electricity being both the most frequently used and most expensive fuel for irrigation pumping. These economies could influence water resource allocation. High costs may stimulate farming innovations that reduce irrigation needs, leaving more water available for withdrawal for other uses.

Industrial Water Use

Water is linked directly to economic development through industrial use. In 1985, industrial and mining uses (other than thermoelectric power generation) required 30.8 billion gallons of freshwater withdrawals each day, or about 9 percent of all water withdrawals (table 3-2). Mining operations actually accounted for about one-tenth of this use category. Water for industry and mining comes from surface sources (19.7 BGD), public supply (5.8 BGD), and groundwater sources (5.3 BGD). Surface and ground sources are supplied by the industries. In 1985, industry and mining also used over 4 BGD of saline water and industry used 144 million gallons daily (MGD) in reclaimed sewage. Most of the water used in industrial processes was returned to a water source and only 19.5 percent was consumed. Water withdrawals for industrial use are heavy in the Great Lakes, Ohio, Mid-Atlantic, and South Atlantic-Gulf water resources regions. Withdrawals for mining are especially high in the California, Missouri, Ohio, and South Atlantic-Gulf regions.

A variety of industrial processes require water:[15]

- Cleansing raw materials
- Transporting materials from one operating stage to another
- Cooking, dissolving, and digesting materials
- Providing a medium for chemical and biological reactions
- Washing filtered materials
- Quenching and cooling equipment and final products
- Cooling and scrubbing process gases and vapors
- Incorporating water in the final products
- Flushing equipment and operating areas for recovery of products and materials

Table 3-6 provides water requirements for many different industrial processes.[16] The amount of water used is directly linked to the unit of production. The production of one car, for example, requires 36,000 gallons of water; the production of one ton of paper requires 130,000 gallons of water. To produce even a single barrel of a malt beverage requires 1,500 gallons of water. Innovations that reduce the per-unit water requirements in these types of processes can be highly cost-effective and can save large quantities of water.

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[15] Brent Blackwelder and Peter Carlson, *Survey of the Water Conservation Programs in the Fifty States: Model Water Conservation Program for the Nation* (Washington, DC: Bureau of Reclamation, U.S. Department of the Interior, 1982), 55.

[16] K. L. Kollar and Patrick MacAuley, "Water Requirements for Industrial Development," *American Water Works Association Journal* 72, no. 1 (January 1980): 5.

As reported in table 3-7, of all the many different American manufacturing processes, the production of primary metals requires the greatest amount of water, about 17.6 BGD of fresh water or 34 percent of all manufacturing needs. Chemical and paper production also are high water-use processes. Table 3-8 reports the principal uses of water--cooling, processing, boilers, sanitation, and other--in various production processes. For example, 70 percent of the water used in primary metal production is for cooling purposes, while in paper production most of the water is used in the actual processing of the paper.

Water Use for Energy Development

Water plays a role in the development of most energy forms. Water for energy development involves both instream and offstream uses. Hydroelectric power production is the principal instream use. The principal offstream use is for cooling in thermoelectric power plants. The intersection of water and electrical energy is also relevant from a public utility perspective because both are regulated sectors that at times compete for scarce water resources.[17]

Water used in the production of electricity from fossil fuels, geothermal power, or nuclear energy constitutes the thermoelectric category. Water withdrawals for thermoelectric power generation rival those for agricultural use. The Geological Survey estimated that thermoelectric power generation accounted for 131 BGD in freshwater withdrawals for 1985 (table 3-2). Over 99 percent of this water is self-supplied from surface sources; only .1 percent is water from public supplies. Thermoelectric power

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[17] Electric Power Research Institute, "Water Water Everywhere But...," *EPRI Journal* 4, no. 8 (October 1979): 6-13.

TABLE 3-6

INDUSTRIAL WATER USE BY TYPE OF PROCESS

Industry	Water Use and Metric
Meatpacking	3.6 gallons/pound carcass weight
Poultry dressing	11.6 gallons/bird poultry slaughter
Dairy products	0.9 gallons/pound
Canned fruits and vegetables	225.0 gallons/case
Frozen fruits and vegetables	11.2 gallons/pound
Wet corn milling	416.0 gallons/bushel of corn grind
Cane sugar	28,100.0 gallons/ton
Beet sugar	33,100.0 gallons/ton
Malt beverages	1,500.0 gallons/barrel
Textile mills	34.0 gallons/pound fiber consumption
Sawmills	5.4 gallons/board-foot lumber
Pulp and paper mills	130,000.0 gallons/ton
Paper covering	6,600.0 gallons/ton paper converted
Alkalis and chlorine	29,800.0 gallons/ton
Industrial gases	636.0 gallons/cubic feet gases
Inorganic pigments	97,800.0 gallons/ton
Industrial inorganic chemicals	14,500.0 gallons/ton 100 percent basic
Plastic materials and resins	24.0 gallons/pound
Synthetic rubber	55.0 gallons/pound
Cellulosic man-made fibers	231.0 gallons/pound
Organic fibers, noncellulosic	101.0 gallons/pound
Paints and pigments	13.0 gallons/gallon
Industrial organic chemicals	125,000.0 gallons/ton
Nitrogenous fertilizers	28,506.0 gallons/ton
Phosphatic fertilizers	35,602.0 gallons/ton
Carbon black	4.8 gallons/pound
Petroleum refining	1,851.0 gallons/barrel crude oil input
Tires and inner tubes	518.0 gallons/car or truck tire
Hydraulic cement	1,360.0 gallons/ton
Steel	62,600.0 gallons/ton steel net production
Iron and steel foundries	12,400.0 gallons/ton ferrous castings
Primary copper	53.0 gallons/pound
Primary aluminum	49.0 gallons/pound
Automobiles	36,500.0 gallons/domestic car

Source: K. L. Kollar and Patrick MacAuley, "Water Requirements for Industrial Development," *American Water Works Association Journal* 72, no. 1 (January 1980), 5.

TABLE 3-7

USES OF WATER IN MANUFACTURING

Industry*	Freshwater Use in Million Gallons Daily	Percent
Primary metals (33)	17,571	34
Chemical and allied products (28)	13,458	26
Paper and allied products (26)	8,438	17
Food and kindred products (20)	2,578	5
Petroleum and coal products (29)	2,528	5
Transportation equipment (37)	1,333	3
Textile mill products (22)	561	2
All other	4,740	9

Source: U.S. Department of the Interior as reported in Brent Blackwelder and Peter Carlson, *Survey of the Water Conservation Programs in the Fifty States: Model Water Conservation Program for the Nation* (Washington, DC: Bureau of Reclamation, U.S. Department of the Interior, 1982), 57.

* Standard industry classification.

TABLE 3-8

TYPES OF WATER USE IN MANUFACTURING

Industry*	Type of Use Cooling	Process	Boiler	Sanitary	Other
Primary metals (33)	70%	27%	2%	1%	0%
Chemical and allied products (28)	81	13	5	1	0
Paper and allied products (26)	34	61	4	1	0
Food and kindred products (20)	50	37	9	5	0
Petroleum and coal products (29)	67	7	18	0	8

Source: U.S. Department of the Interior as reported in Brent Blackwelder and Peter Carlson, *Survey of the Water Conservation Programs in the Fifty States: Model Water Conservation Program for the Nation* (Washington, DC: Bureau of Reclamation, U.S. Department of the Interior, 1982), 59.

* Standard industry classification.

production also accounted for the use of 56 BGD in saline water in 1985, or about 30 percent of all water used.[18] The total amount of fresh and saline water used, 187 BGD, produced 2,140,000 gigawatt-hours (GWh) in thermoelectric power. More than any other use category, however, water used for thermoelectric power generation is returned to a water source. Only 3.3 percent of freshwater water withdrawals for this purpose are consumed. The Great Lakes, Ohio, Mid-Atlantic, and South Atlantic-Gulf water resources regions make significant withdrawals for power generation.

In addition to offstream uses, hydroelectric power production in 1985 required the instream use of 3,100 billion gallons of water daily for the production of 296,000 GWh in power.[19] The Pacific Northwest used 1,200 BGD to generate 133,000 GWh in 1985. The Great Lakes used 456 BGD to generate 31,700 GWh in the same year. Several other water resource regions in the central and eastern United States, however, also have significant hydroelectric power development.

Thermoelectric power production is not the only energy development process requiring water. Extracting and refining fossil and nuclear fuels and developing synthetic fuels also make significant demands on water supplies. Table 3-9 provides the amount of consumptive use of water that is required by different energy production processes. The table reports the number of liters of water needed in each process to produce the equivalent of one ton of oil and to produce one kilowatt hour of energy. Steam electric power generation requires by far the greatest amount of water per ton of oil equivalent or per kilowatt hour of any of the energy production processes. The demand for water in energy development may become a more critical issue as shortages are experienced in either water or energy or both. And water for energy must still compete with other water uses.

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[18] Solley, Merk, and Pierce, *Estimated Use of Water in the United States*, 38.
[19] Ibid.

TABLE 3-9

ENERGY DEVELOPMENT AND WATER CONSUMPTION

Process	Consumptive Use: Liters per Ton of Oil Equivalent	Consumptive Use: Liters per kWh
Extraction		
Coal mining, surface	81	0.007
Coal mining, underground	100	0.009
Coal beneficiation	170	0.015
Oil production, secondary recovery	1,100	0.09
Oil production, tertiary recovery	4,900	0.42
Gas processing and transportation	240	0.02
Oil shale, mining, and surface processing	4,700	0.40
Oil shale, modified in-situ recovery	1,300	0.11
Tar sands, mining, and surface treatment	3,000	0.26
Refining		
Oil refining	1,200	0.10
Nuclear fuel cycle		
Uranium mining	9	0.001
Uranium milling	410	0.035
Uranium hexaflouride conversion	20	0.002
Enrichment, gas centrifuge	73	0.006
Enrichment, gaseous diffusion	490	0.042
Fuel fabrication	33	0.003
Fuel reprocessing	20	0.002
Steam-electric power generation (a)		
Fossil-fueled, evaporative cooling demand only	27,000	2.3
Coal-fired, including ash disposal & miscellaneous	31,000	2.7
Nuclear, light-water reactor	35,000	3.0
Geothermal, vapor-dominated systems	80,000	6.9
Geothermal, water-dominated systems	174,000	15.0
Synfuels production (b)		
Coal gasification	3,000	0.026
Coal liquefaction	1,600	0.14
Solid-fuel production	920	0.08

Source: George H. Davis, *Water and Energy: Demand and Effects* (Belgium: United Nations Educational, Scientific, and Cultural Organization, 1985), appendix C. Values are unweighted.

(a) Assumes closed cooling system with cooling water towers and thermal efficiency as follows: fossil-fueled at 36%, nuclear at 31%, vapor-dominated geothermal at 15%, and water-dominated geothermal at 7-9%.
(b) Assumes intermediate wet-cooling demand.

Projections of Water Demand

According to a study sponsored by Resources for the Future, "the art of making comprehensive projections remains more primitive for water than for a number of other resources commodities" because:[20]

- Most water problems are local and regional rather than national in scale.
- There is no comprehensive market for water.
- Water from the same source is used for a variety of purposes and these uses affect the supply in different ways.
- Because water quantity and water quality are so closely tied, water quantity alone is often an inadequate measure of water supply.

The rate of technological advancement, changes in economic conditions, shifts in national and international politics, and the unpredictability of human events all contribute to the uncertainty of projections.[21] Not surprisingly, discrepancies in assessments of water demand can be dramatic. Several different water withdrawal and consumption forecasts for the nation made in the late-1960s and middle-1970s are reported in figures 3-3 and 3-4. Projections of withdrawals and consumption were made by the following organizations:

- Water Resources Council: WRC (1968) and WRC (1975)
- National Water Commission: NWC
- Resources for the Future: RFF
- Senate Select Committee on National Water Resources: Sen. Select Comm.

For all of these analyses, the historic data come from U.S. Geological Survey studies and represent freshwater withdrawals only. For projected withdrawals in figure 3-3, however, the estimates by RFF, NWC, and WRC (1968) include both fresh and saline water. All projections of consumption reported in figure 3-4 are for freshwater only.

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[20] N. Wollman and G. E. Bonem, *The Outlook for Water-Quality, Quantity and National Growth* (Baltimore, MD: Resources for the Future and The Johns Hopkins Press, 1971), as cited by Warren Viessman, Jr. and Christine DeMoncada, *State and National Water Use Trends to the Year 2000* (Washington, DC: Congressional Research Service, Library of Congress, April 1980), 273.

[21] Viessman and DeMoncada, *State and National Water Use Trends*.

The Water Resources Council made water-use projections in 1968 and in 1975. The 1975 estimate was based on the assumption that strict water quality laws would give the manufacturing and electric power industries an incentive to recycle water, thereby reducing water withdrawals. The WRC also expected water withdrawals for irrigation to decrease due to depletion of groundwater in the Southwest. WRC acknowledged, however, that the data used for its projections was often general and of varying reliability, and cautioned that its projections should only be used as an indicator of trends in use and that other estimates of water use should also be considered.

In an effort to take into account the many different factors affecting future water demand, the National Water Committee used multiple variables--including population, per capita energy consumption, recreational water uses, and price of water--to construct "alternative futures" of national water needs. Using different assumptions about the input variables, the NWC provided projections of low, middle, and high water-use trends. The "high" projection assumed very high water use for steam electric cooling. The Congressional Research Service concluded that this projection could be considered the upper limit of possible future water use.[22]

Resources for the Future projected water use for 1980, 2000, and 2020 under assumptions of high, medium, and low economic growth rates. (The low growth projection is not included in figures 3-3 and 3-4.) These projections were intended to be used as indicators of water use problems that would occur if current trends continued. Using projections for population, the Gross National Product, and other indexes, RFF estimated water use in different categories, including municipal use, rural domestic use, food manufacturing and processing, and irrigation. It was assumed that steam electric power withdrawals would gain on withdrawals by agriculture and, under the high projection, overtake agriculture by the year 2020. It was also assumed that agriculture would account for only 52 percent of all water consumption in 2020, compared to 87 percent in 1960.

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[22] Ibid., 241.

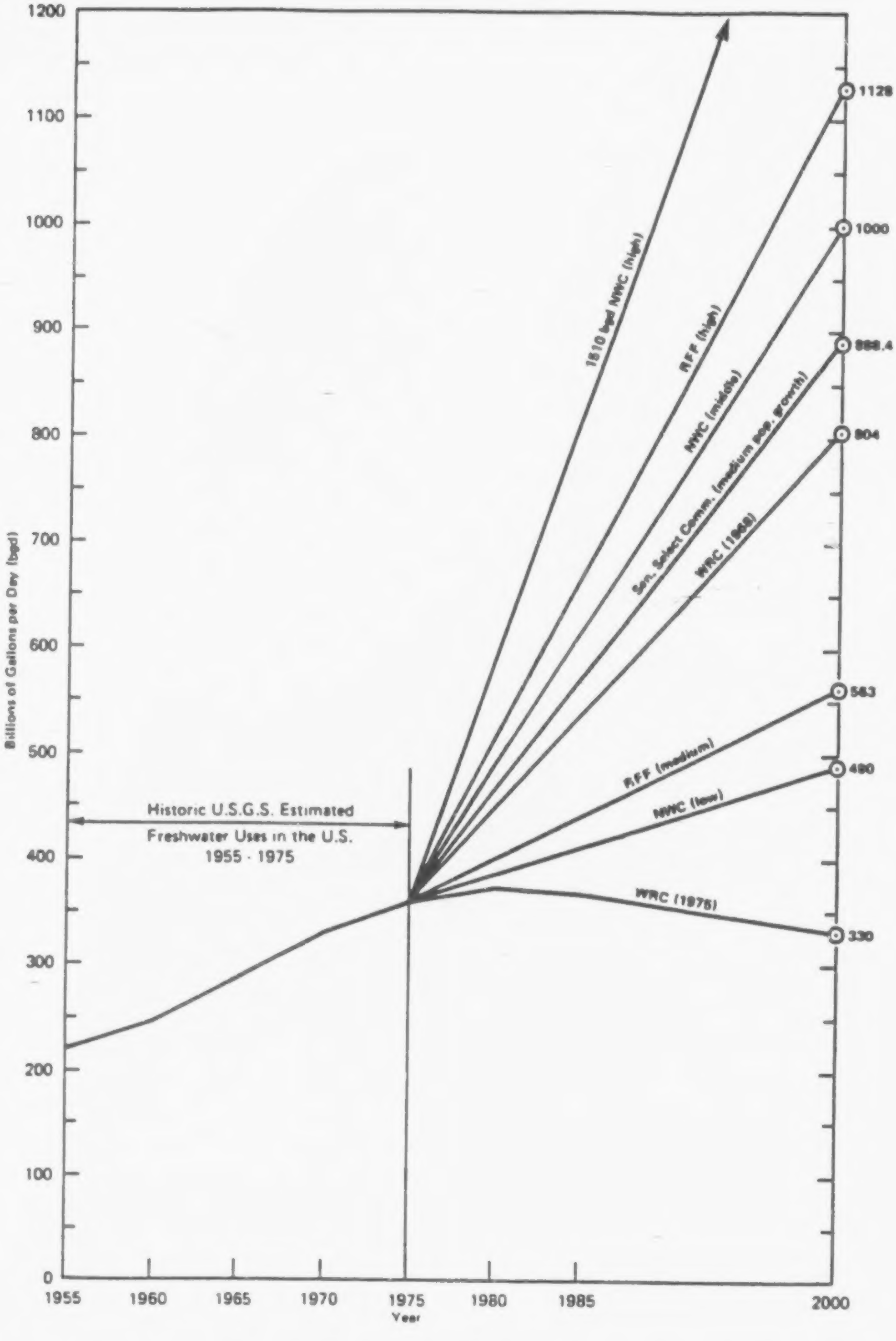

Fig. 3-3. Historic and projected water withdrawals for the United States, 1955-2000, as depicted in Warren Viessman, Jr. and Christine DeMoncada, *State and National Water Use Trends to the Year 2000* (Washington, DC: Congressional Research Service, Library of Congress, 1980), 236.

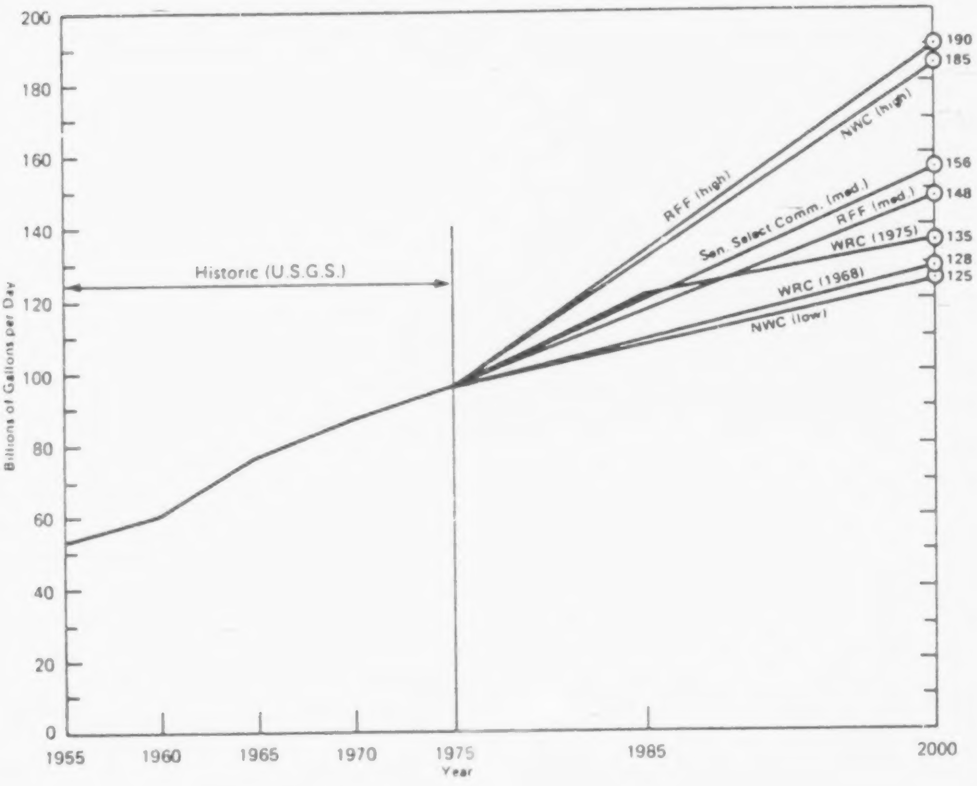

Fig. 3-4. Historic and projected freshwater consumption for the United States, 1955-2000, as depicted in Warren Viessman, Jr. and Christine DeMoncada, *State and National Water Use Trends to the Year 2000* (Washington, DC: Congressional Research Service, Library of Congress, 1980), 237.

The Senate Select Committee projections, made in 1961, indicated that freshwater withdrawals would increase by 250 percent between 1975 and 2000 and that consumption would increase 162 percent over the same period. According to the Congressional Research Service report, the assumptions used in the Senate's estimate reflect the "growth" attitude that prevailed at the time it was made. The Committee assumed that the economy would grow at the same rate as in the past, that adequate water supplies would be available under the prevailing general pricing policies, that industrial water use would grow at a high rate, and that water efficiency would improve for irrigation but would not improve in other water-use categories.

Resources for the Future compared its estimates to those of the Senate Select Committee and highlighted the similar conclusions that each had made:

- The Southwest is projected to be a hard-core water shortage area;
- Costs of treatment will dominate future outlays for water if streams are to be kept aerobic;
- A relatively large amount of flow is required to dilute wastes after treatment has been carried to levels that are twice or more the present level;
- Because of required dilution flows, water shortage will spread eastward; and
- Unless large-scale transbasin movements of water are undertaken in the West, most of the expenditures on water from now on will be for waste treatment and flow regulation in the East.[23]

The most detailed and frequently cited assessment of future water needs is the Second National Assessment by the Water Resources Council, published in 1978.[24] Table 3-10 provides estimates for water withdrawal and water consumption in base year 1975 and 2000 compiled by the Oak Ridge National Laboratory for the assessment.[25] The projections indicated that between 1975 and 2000, more water withdrawals and water consumption were expected for domestic and commercial, livestock, and minerals industry uses. Fewer withdrawals were expected for the steam electric and manufacturing industries, even though the amount of water consumed by these industries was expected to increase. Irrigation was projected to require fewer water withdrawals and to hold steady for the amount of water consumed.

Table 3-11 provides estimates of freshwater withdrawals and consumption according to the nation's water resources regions. Decreases in withdrawals between base year 1975 and the year 2000 are anticipated for thirteen water resource regions in the nation. On the other hand, the consumptive use of water is expected to increase for the majority of regions, meaning that proportionately more water will be consumed and less will be returned to water sources. State-level data on withdrawals and consumption for base year 1975 and projections for the year 2000 from the Second National Assessment are reported in appendix A of this report.

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[23] Wollman and Bonem, *The Outlook for Water-Quality, Quantity and National Growth*, as cited by Viessman and DeMoncada, *State and National Water Use Trends*, 240.

[24] U.S. Water Resources Council, *The Nation's Water Resources, 1975-2000, Volumes 1-4*.

[25] Oak Ridge National Laboratory, *State Water Use and Socioeconomic Data Related to the Second National Water Assessment* (Washington, DC: U.S. Water Resources Council, 1980).

The Water Resources Council suggested that improved water use efficiency would result in future reductions of water withdrawals. The Council estimated that increased efficiency and water recycling will change the national ratio of water-consumption-to-water-withdrawal from 32 percent in the study's 1975 base year to 44 percent by the year 2000 as agriculture and industry reduce water withdrawals and return flows.[26]

Forecasting Water Demand

Forecasting water demand is no simpler than forecasting any other type of demand. Moreover, the intricate relationship between water supplies and water demand can complicate matters. Spells of dry weather, for example, may not only impair supplies but also lead to high levels of water use.

Forecasting serves several short-term and long-term purposes.[27] In the short-term, forecasting facilitates financial planning and management, projecting revenue receipts to assess if and when a rate change is needed, estimating cost of service and setting rates, and risk management. In the long term, forecasting assists in developing a long-term financial strategy for the water supplier, planning the water system, and setting objectives for rates and policy. These goals may be held not only by water utilities but by their regulators as well.

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[26] U.S. Water Resources Council, *The Nation's Water Resources 1975-2000, Volume 2*, part III, 2.

[27] G. S. Saleba (1985) as reported in David W. Prasifka, *Current Trends in Water-Supply Planning* (New York: Van Nostrand Reinhold Company, 1988), 63.

TABLE 3-10

FRESHWATER WITHDRAWALS AND CONSUMPTION
FOR BASE YEAR 1975 AND PROJECTED FOR THE YEAR 2000,
BY TYPE OF USE

	Withdrawals			Consumption		
	Mil. Gal. Daily		Percent	Mil. Gal. Daily		Percent
Water Use Category	1975	2000	Change	1975	2000	Change
Total domestic*	23,253	30,330	30	6,267	8,073	29
Publicly supplied	21,162	27,929	32	4,975	6,637	33
Self-supplied	2,092	2,401	15	1,292	1,436	11
Total commercial	5,529	6,731	22	1,109	1,362	23
Total agricultural	160,141	156,078	-3	88,029	94,864	8
Irrigation	158,229	153,527	-3	86,117	92,313	7
Livestock	1,912	2,551	33	1,912	2,551	33
Total manufacturing	50,624	19,494	-61	5,667	14,575	157
Primary metals	17,556	3,503	-80	1,932	2,771	43
Chemicals	13,366	5,105	-62	1,181	3,992	238
Paper	8,396	5,356	-36	833	4,247	410
Food, etc.	2,639	1,185	-55	365	794	118
Petroleum	2,375	1,205	-49	576	964	67
Transportation	1,145	534	-53	161	409	154
Textile mills	587	215	-63	67	146	118
All other	4,560	2,391	-48	528	1,194	126
Total minerals	7,024	11,282	61	2,192	3,603	64
Nonmetals	3,655	6,077	66	539	1,015	88
Fuels	2,552	3,844	51	1,359	2,075	53
Metals	817	1,361	67	294	513	74
Steam electric	88,735	79,692	-10	1,413	10,537	646
Total freshwater	335,306	303,606	-9%	104,677	133,015	27%
Total saline water	55,657	116,489	109%	302	2,514	732%
Total water	390,963	420,095	7%	104,979	135,529	29%

Source: Adapted from Oak Ridge National Laboratory, *State Water Use and Socioeconomic Data Related to the Second National Water Assessment* (Washington, DC: U.S. Water Resources Council, 1980), Section B.

* This data source refers to publicly supplied water as central water and self-supplied water as noncentral water.

TABLE 3-11

FRESHWATER WITHDRAWALS AND CONSUMPTION FOR BASE YEAR 1975 AND PROJECTED FOR THE YEAR 2000, BY WATER RESOURCES REGION

	Withdrawals			Consumption		
	Mil. Gal. Daily		Percent Change	Mil. Gal. Daily		Percent Change
Region	1975	2000		1975	2000	
New England	5,098	3,230	-37	481	1,063	121
Mid-Atlantic	18,300	13,873	-24	1,843	3,548	93
South Atlantic-Gulf	24,510	28,340	16	4,867	10,053	107
Great Lakes	42,813	25,623	-40	2,598	4,693	81
Ohio	34,934	16,925	-52	1,798	4,332	141
Tennessee	7,412	6,013	-19	313	1,105	253
Upper Mississippi	12,401	7,910	-36	1,145	2,688	135
Lower Mississippi	14,567	24,841	71	4,027	5,511	37
Souris-Red-Rainy	336	587	75	112	446	298
Missouri	38,016	44,359	17	15,469	19,913	29
Arkansas-White-Red	12,868	13,337	4	8,064	8,887	10
Texas-Gulf	16,925	14,991	-11	11,259	10,529	-6
Rio Grande	6,321	5,633	-11	4,240	4,016	-5
Upper Colorado	6,869	7,519	9	2,440	3,232	32
Lower Colorado	8,917	7,857	-12	4,595	4,708	2
Great Basin	7,991	7,258	-9	3,779	4,036	7
Pacific Northwest	37,495	33,852	-10	11,913	15,196	28
California	39,636	41,265	4	26,641	29,699	11
Alaska	305	745	144	58	459	691
Hawaii	1,879	1,349	-28	605	666	10
Caribbean	907	890	-2	343	300	-13
TOTAL*	338,500	306,397	-9	106,590	135,080	27

Source: Adapted from U.S. Water Resources Council, *The Nation's Water Resources, 1975-2000, Volume 1: Summary* (Washington, DC: U.S. Water Resources Council, 1978), 48.

* Figures may not add to totals because of independent rounding.

Numerous methods of forecasting are available for general planning and policy analysis purposes. There are also methods specifically designed for forecasting water demand during periods of drought.[28] Three approaches to water forecasting are described briefly below.

Extrapolation of Time-Series Data

Analysts using the extrapolation method place great faith in historical demand patterns to predict future demand patterns. Estimating future demand in this manner usually assumes linear or slightly curvilinear growth in demand and makes no attempt to predict deviations of a significant magnitude. One of the key problems with this method is that the period of demand used as the basis for extrapolation greatly affects demand projections, even from year to year. Frequent adjustments to the forecast may be required, and planning may be greatly hindered.

The extrapolation method is especially weak when accounting for the changes in different components of water use. One study points out, for example, that extrapolation assumes continuous growth in all use categories, including leakage and unaccounted-for water, even though this assumption is not necessarily valid.[29] Nor does extrapolation account for efficiency gained through innovations in technologies, economies of scale, management, planning, or even regulation.

Statistical, Econometric, and Stochastic Models

Forecasts of water demand do not have to rely solely on the pattern of historical demand. Several modeling techniques allow researchers to make forecasts based on projections of explanatory variables that are known to correlate with water demand. The U.S. Army Corps of Engineers has identified six basic types of water forecasting methods.[30] They are: per capita methods, per connection methods, unit-use coefficient methods, multivariate requirements models, demand models, and probabilistic methods.

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[28] Benedykt Dziegielewski, Duane D. Baumann, and John J. Boland, *The Evaluation of Drought Management Measures for Municipal and Industrial Water Supply* (Fort Belvoir, VA: Institute for Water Resources, U.S. Army Corps of Engineers, 1983).

[29] George Archibald, "Demand Forecasting in the Water Industry," in Vince Gardiner and Paul Herrington, eds., *Water Demand Forecasting* (Norwich, UK: Geo Books, 1986).

The first three are statistical methods that employ only single explanatory variables. Per capita methods use population only for predicting water use. As such they are criticized for excluding other known factors influencing water demand and possible differences among usage categories. The per connection method is also limited to a single explanatory variable, but has the advantages of better data availability and a closer correspondence to the number of households in the utility service territory. Unit-use methods apply single explanatory variables, other than population size or service connections, to total water use or disaggregated categories, such as residential use. An example would be a method relating the number of manufacturing sector employees to industrial water use.

Requirements models and demand models are both econometric (or multiple coefficient) methods that incorporate more than one explanatory variable. Requirements models use variables that are significantly correlated with water use. Demand models incorporate price, income, and other variables while emphasizing economic reasoning, causality, and the statistical significance of coefficients. Because they provide a more comprehensive picture, multivariate models are usually regarded as more useful for planning purposes. These also may be more or less complicated, which in turn affects the degree of difficulty in acquiring and analyzing the necessary data. Moreover, time-series forecast models require forecasts of explanatory variables, such as population forecasts. If the population forecast is off the mark, the forecast of water demand likewise will be off. The planning process may suffer as a consequence.

One way to consider uncertainty in forecasting is to use a stochastic or probabilistic approach, such as a contingency tree or a "what if" analysis, in combination with another base forecasting method. A contingency tree takes into account different combinations of variables, based on different probability assumptions, and makes it possible to produce alternative demand forecasts. The result actually is a range of forecasts to which different probabilities may be assigned. In a sophisticated analysis, such as one using a simulation model, both supply and demand could be manipulated to arrive at alternative forecasts. This may be an especially useful tool in planning for the possibility of drought or other water shortages. Proposed measures to mitigate the effects of a shortage, such as rationing, could be incorporated within the model to assess their impact. However, probabilistic methods tend to involve significant data demands. While they may enhance planning efforts, they also add a high degree of complexity to the process.

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[30] John J. Boland, et al., *Forecasting Municipal and Industrial Water Use: A Handbook of Methods* (Fort Belvoir, VA: Institute for Water Resources, U.S. Army Corps of Engineers, 1983).

Each of the methods described by the Corps of Engineers has certain advantages. A single-coefficient method, for example, may serve the purposes of preliminary assessments. Probabilistic methods are too complex for this purpose but have advantages in terms of other planning criteria. The amount of data required and its availability, however, depends on the particular application.

End-Use Methods

The alternative approaches to forecasting water use include end-use or component methods that emphasize estimating different water use categories and adding these to arrive at an aggregate demand forecast. A range of values is sometimes used within components and for the aggregate amount. For example, four general categories of water demand used in an end-use study by the Severn-Trent Water Authority in Great Britain are: domestic use, industrial and commercial use, agricultural use, and unaccounted-for water.[31] Components of domestic use include personal use, toilet flushing, clothes washing, dish washing, other appliance use, and outdoor use. Industrial and commercial use consists of domestic uses as well as processing and direct and recycled cooling. Agricultural use can be divide into domestic, livestock, and irrigation uses. Finally, unaccounted-for water may be attributable to customer connections, the distribution system, trunk mains, and service reservoirs.

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[31] Archibald, "Demand Forecasting in the Water Industry," in Gardiner and Herrington, eds., *Water Demand Forecasting*.

In an end-use model, the different components of each general category are forecast according to expectations about that type of use. Domestic use, for example, may be affected by changes in plumbing codes or the degree of market saturation for different water-using appliances. The introduction of metering or an alternative rate schedule may affect the consumption patterns of industrial and commercial users. The availability of alternative sources (such as self-operated wells) might affect agricultural use. A leak detection and repair program could affect the unaccounted-for water category. In each case, the method can accommodate these expectations and produce a range of estimates that takes into account their effect on total water consumption. End-use methods also can accommodate changes in the behavior of water users or in the water fixtures or technologies they use. Installing low-volume toilets in a housing development or implementing water recycling at an industrial plant are examples.

The best approach to water demand forecasting may be a hybrid approach that provides the policy analyst with a means of verifying the validity and reliability of the models and resulting forecasts. This is particularly important when data may be insufficient. Further, the use of any stochastic technique that allows the planner to assess alternative contingencies is likely to enhance planning capabilities. Table 3-12 compares time-series, econometric, end-use, and hybrid forecasting techniques in terms of advantages and disadvantages.

Data Requirements

Regardless of what is being modeled (requirements, demand, or end use) and whether a stochastic approach (such as a contingency tree) is being incorporated, econometric modeling requires a set of explanatory variables.

Table 3-13 provides some of the variables that may be used in projecting future water needs for a given locality or water utility service territory. Each variable is thought to play a role in determining water needs. Analysts, of course, choose a set of explanatory variables that they believe are the best predictors. Four major categories are identified. Resource utilization consists of land use and water use variables. The socioeconomic category consists of demographic, economic, and housing variables. Cultural and institutional variables encompass both cultural and legal/political variables. Finally, water system variables pertain to the operational and technological as well as the costs and revenues of water providers. In addition, forecasts may take into account some of the water supply forecast parameters, such as the hydrologic, topographic, and climatic variables highlighted in chapter 2. Possible data sources for use in water demand forecasting, divided according to historical and projected variables, are presented in table 3-14.

Some variables that are difficult to quantify may have a significant effect on water consumption rates. David W. Prasifka suggests that, besides rainfall, the following factors should be considered:[32]

- Variations in lawn irrigation demands associated with differences in residential density.
- Differences in greenbelt irrigation requirements and in the availability of untreated or reclaimed water for these needs.
- Differences in the degree to which structural and nonstructural water conservation measures have been implemented in the area.
- Variations in the person/household ratio.
- Variations in the concentration of water-intensive industrial and commercial land uses.
- Effectiveness of public education programs to increase consumer awareness.
- Variations in income levels and other economic criteria.
- Intensity of construction activity, such as grading and site work.

Some of these factors may help explain variations in short-term demand. Seasonal, daily, and hourly demand fluctuations are normally expressed in terms of peaking factors and quantified as a percentage of average demand.[33]

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[32] Prasifka, *Current Trends in Water-Supply Planning*, 10.

[33] Ibid.

TABLE 3-12

COMPARISON OF ALTERNATIVE DEMAND FORECASTING METHODS

Time-Series
- Advantages
  - Minimal data requirements
  - Low cost
  - Forecast accuracy generally good in short run
  - Can predict seasonal and daily patterns
- Disadvantages
  - Does not treat underlying factors explicitly
  - Not useful for policy analysis
  - Accuracy low in the long run

Econometric
- Advantages
  - Explicitly models underlying influences on demand
  - Based on explicit theory of consumer behavior
  - Less data-intensive than end-use models
- Disadvantages
  - High skill level required to develop models
  - Difficult to address or impossible to identify individual variable impacts (e.g., multicolinearity)

End-Use
- Advantages
  - Good policy-analysis capabilities
  - Relatively understandable
- Disadvantages
  - Often lacks endogenous behavioral component
  - Data-intensive
  - Costly

Hybrid
- Advantages
  - Better behavioral component than pure end-use models
  - Better policy analysis capabilities than most econometric models
- Disadvantages
  - Data-intensive
  - Costly
  - Ad hoc nature can make interpretations difficult
  - Can lack efficiency and elegance

Source: S. S. George (1985) as reported in David W. Prasifka, *Current Trends in Water Supply Planning* (New York: Van Nostrand Reinhold Company, 1988), 98.

TABLE 3-13

SELECTED VARIABLES USED IN WATER DEMAND FORECASTING

Categories	Variables
Resource Utilization	
Land Use	Fractions of land in various use categories (such as urbanized, cropland, woodland)
	Agricultural production statistics
	Recreational uses
Water Use	Water use by self-supplied industry
	Water use by agricultural sector
	Recreational uses
	Irrigated areas
Socioeconomic	
Demographic	Population (number of households, number of connections, number of users, etc.)
	Household size
	Characteristics of the population
Economic	Income level (persons or households)
	Assess sales value of residential properties
	Size of residential properties
	Number of commercial and institutional establishments
	Value of commercial receipts
	Employee productivity (industrial water use)
	Price elasticities for water demand
Housing	Housing density
	Type of housing
	Construction grading
	Size of lots
	Connections to public sewer
Cultural/Institutional	
Cultural	Consumer preferences, habits, and tastes
	Acceptability of demand reduction measures by customers
	Cultural constraints or incentives
	Consumer education
	Policy variables
Legal/political	Legal barriers to implementation of alternatives
	Political constraints and opposition
	Historical experience

TABLE 3-13--Continued

Categories	Variables
Water System	
Operational	Historical water use Total treated water Total delivered water Daily reservoir levels
Technological	Inspection and repair of faulty plumbing Leak detection program Efficiency of water-using equipment Distribution pressure Supply dependability Allocating water of different quality to different users Water reuse, recycling, and recirculation (industrial) Industrial processes and applications
Costs and Revenues	Operation and maintenance costs of water-supply system Investment and operation-maintenance costs for alternative water-supply sources Water and sewer revenues Water and sewer rate structures Width and level of price blocks Water and sewer revenues (by customer class)

Source: Authors' construct based on J. J. Boland, et al., *Forecasting Municipal and Industrial Water Use: A Handbook of Methods* (Fort Belvoir, VA: Institute for Water Resources, U.S. Army Corps of Engineers, 1983); B. Dzielielewski, D. D. Baumann, and J. J. Boland, *Prototypical Application of a Drought Management Optimization Procedure to an Urban Water Supply System* (Fort Belvoir, VA: Institute for Water Resources, U.S. Army Corps of Engineers, 1983); and David W. Prasifka, *Current Trends in Water Supply Planning* (New York: Van Nostrand Reinhold Co., 1988).

TABLE 3-14

SELECTED DATA SOURCES USED IN WATER DEMAND FORECASTING

Type of Data	Possible Data Sources
Historical Data	
Water use data and number of connections	Water utility
Population data	U.S. Census of Population or Housing State, regional, or local planning agency Economic development agency City or regional planning agency Water utility
Number of households or dwelling units and other demographic variables	U.S. Census of Population or Housing State, regional, or local planning agency U.S. Department of Commerce
Climatic data	National Weather Service National Oceanic & Atmospheric Administration U.S. Department of Commerce Department of Meteorology or Climatology at a state university Water utility
Water and wastewater rate structures	Water utility Water rate authority or regulatory agency
Other economic variables	State, regional, or local planning agency U.S. Census of Population, Housing, Business, or Manufactures Real property assessment agency
Policy variables	State or local governments State or local planning agencies Water rate authority or regulatory agency Water utility
Manufacturing employment, output, and processes	Local or regional economic development agency State employment agency U.S. Census of Manufactures U.S. Bureau of Labor Statistics Individual firms

TABLE 3-14--Continued

Projected Data	
Population, household size, number of households, etc.	State, regional, or local planning agency Economic development agency Federal projections
Economic variables	State, regional, or local planning agency Federal projections
Manufacturing employment	State, regional, or local agency Economic development agency Federal projections Individual firms

Source: Adapted from John J. Boland, et al., *Forecasting Municipal and Industrial Water Use: A Handbook of Methods* (Fort Belvoir, VA: Institute for Water Resources, U.S. Army Corps of Engineers, 1983).

Future Water Demand Issues

Forecasting is likely to be a prominent issue in the coming years. If water becomes scarce or very costly to the users in a region, forecasts will be needed to assist in making some potentially difficult planning choices. The forecast itself could become the center for disputes over future water needs and the best way to meet them. Controlling demand is viewed by some as an alternative to adding supply capacity. Demand management, of course, requires an investment of resources for both planning and implementation.

Neither undersupply nor excess capacity is an appealing prospect for a public utility or its regulators, as has been well demonstrated in the electricity, natural gas, and telecommunications industries. Accurate forecasting and flexible planning can reduce the risk of these situations. The prospect of occasional shortage may make it necessary to evaluate water use priorities, including those types of demand most able to withstand use restrictions.

Pricing (discussed more fully in chapter 8) is another demand issue because of the potential for elasticities to effect demand levels. Pricing may also be advocated as a conservation tool. Conservation technologies and behaviors will affect demand, but differently for different categories of users. As competition for water intensifies, patterns of demand among water-user categories may also change, particularly if water markets emerge. Finally, demand may come to be thought of as a leading cause of water shortage, and at least as important as supply causes, particularly during times of drought. The nature and impact of droughts, and how to mitigate them, is the subject of subsequent chapters.

CHAPTER 4

DROUGHT AND ITS EFFECTS

In the spring of 1989, President Hussain Muhammad Ershad led the people of Bangladesh in nationwide prayers for rain to end yet another drought. Later in the year, when the rains came. thousands were killed by the tornadoes that came too. The people of South Asia know weather's deadly side. Droughts there alternate with flooding and both are punctuated with episodes of monsoons and cyclones. Each year, scores of people in this region and other corners of the world fall victim to the weather and the thirst, famine, and disease that sometimes follow prolonged periods of bad weather. Drought can threaten human subsistence almost anywhere, but its effect on developing nations is devastating.

Drought expert Ivan Tannehill once observed:

> Famine, war, and disease are pictured in the Book of Revelations as the three deadly enemies of the human race. Drought of itself can bring on a famine. Drought can be a cause of war, which in turn contributes to famine. Drought and crop failure bring undernourishment and starvation, which in turn contribute to disease. The three go together--famine, war, and disease--and in seeking the facts about the results of drought, we find the three so intertwined that they cannot be clearly separated.[1]

Even on the relatively water-rich continent of North America, most regions have experienced drought at one time or another. This chapter provides a general overview of drought and its effects, followed in chapter 5 by a case study of the 1988 drought. How to mitigate the effects of drought is the subject of chapter 6.

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[1] Ivan Ray Tannehill, *Drought: Its Causes and Effects* (Princeton, NJ: Princeton University Press, 1947), 23.

Droughts and Nature

Above all else, drought is a natural phenomenon, a *force majeure*. In this respect, it is like other natural phenomena: earthquakes, floods, tornadoes, hurricanes, tsunamis (high waves), and the like. According to Tannehill:

> Drought is one of the best examples of our helplessness before the broad-scale phenomena of nature. In spite of all the power man has developed, he has not been able to produce in all the world's history enough rain from the free atmosphere by artificial means to water a modest garden at a place and time of his own choosing. We look into a droughty sky knowing full well that the atmosphere contains ample water vapor for our needs, but we have no way of bringing it to earth. We see millions of acres of vegetation slowly burn up, but there is no fire that can be quenched; and even if there were, we would have no water with which to fight it. The rain deficiencies in a major drought amount to billions of tons of water.[2]

Although unique in many ways, drought is only one type of xerasia, or dryness.[3] In fact, there are four general categories of xerasia, as illustrated in figure 4-1. Two key dimensions of dryness are context (water availability) and process (type of environmental transformation). When humans cause a temporary imbalance, water shortages are characteristic. When humans cause permanent deficiencies, desertification occurs. Permanent deficiencies caused by nature are marked by the presence of aridity or deserts. Finally, when nature produces temporary imbalances, the resulting type of xerasia is known as drought. Types of xerasia are not entirely discrete or stable over time. One of the potential long-term effects of drought in combination with human activity is desertification, which is the process of degenerating productive ecosystems into desert.[4]

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[2] Ibid., vii.

[3] Evan Vlachos and L. Douglas James, "Drought Impacts," in Vujica Yevjevich, Luis da Cunha, and Evan Vlachos, eds., *Coping with Droughts* (Littleton, CO: Water Resources Publications, 1983), 44-73.

[4] L. V. da Cunha, E. Vlachos, and V. Yevjevich, "Drought, Environment and Society," in *Coping with Droughts*, 9.

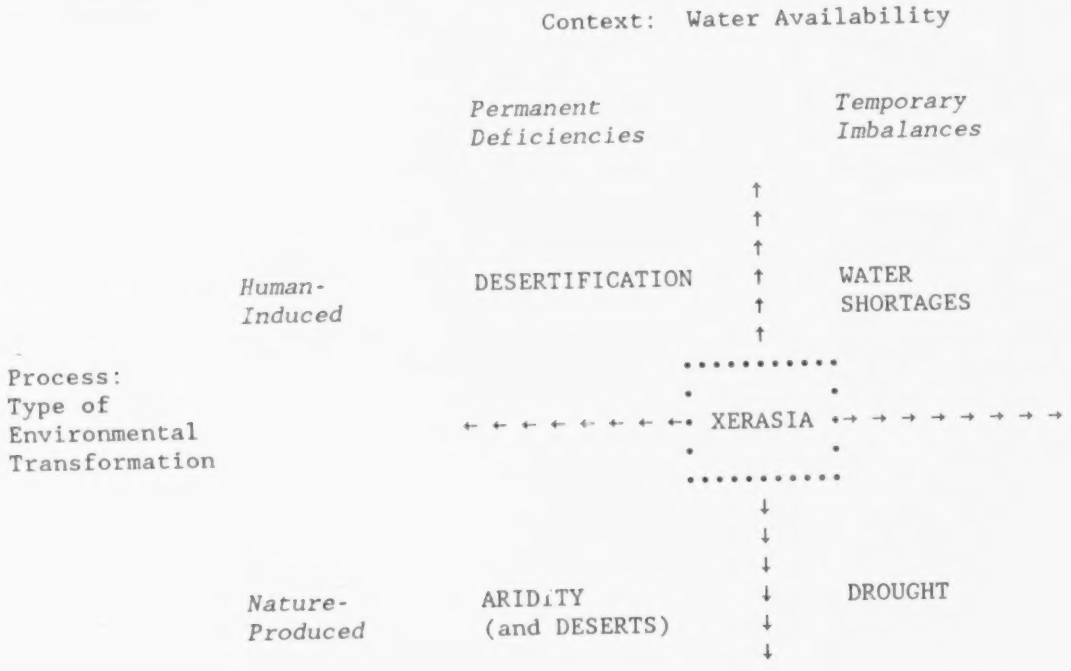
Context: Water Availability
Permanent Deficiencies
Temporary Imbalances
Human-Induced
DESERTIFICATION
WATER SHORTAGES
Process: Type of Environmental Transformation
XERASIA
Nature-Produced
ARIDITY (and DESERTS)
DROUGHT

Fig. 4-1. Categories of dryness (xerasia) as depicted in Evan Vlachos and L. Douglas James, "Drought Impacts," in Vujica Yevjevich, Luis da Cunha, and Evan Vlachos, eds., *Coping with Droughts* (Littleton, CO: Water Resources Publications, 1983), 47.

Each type of xerasia has particular characteristics, effects, and responses, as detailed in table 4-1.[5] The principal characteristics of drought in this classification are: persistent lower-than-average precipitation; uncertain frequency, duration, and severity; unpredictable occurrence; overall diminished water resources; and diminished average carrying capacity of the ecosystem. Its effects include various types of stress on the ecosystem as well as strained water supplies. Finally, responses to drought include resource use regulation and institutional or "crisis-oriented" measures.

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[5] Ibid.

TABLE 4-1

CHARACTERISTICS, EFFECTS, AND RESPONSES FOR TYPES OF DRYNESS

Drought

- Characteristics
  - Persistent lower-than-average precipitation
  - Uncertain frequency, duration, severity
  - Unpredictable occurrence
  - Overall diminished water resources
  - Diminished average carrying capacity of ecosystem
- Effects
  - Deterioration of farm and rangelands; wind erosion
  - Reduction of natural flora and fauna
  - Deterioration of air quality: dust
  - Brush infestation
  - Pest infestation
  - Strained water supplies
- Responses
  - Resource use regulation, rationing and/or recycling
  - Institutional "crisis-oriented" measures

Water Shortages

- Characteristics
  - Groundwater overdraft
  - Reduced reservoir capacities
  - Disturbed soil surface and subsurface: moderate land uses
  - Increased runoff
  - Decreased recharge
  - Altered carrying capacity
- Effects
  - Local hydrological systems affected
  - Deterioration of water quality; saline intrusion, seep
  - Competition among water users
- Responses
  - Resource use regulation, rationing and/or recycling
  - Increased value of water rights
  - Institutional mitigating measures: conservation
  - Technological innovations
  - Changes in land uses: farmland conversions

Aridity

- Characteristics
  - Overall low moisture
  - High solar energy income
  - Extreme temperature variations
  - Highly variable precipitation in time and space
  - Low annual average rainfall
  - Low carrying capacity

TABLE 4-1--Continued

Aridity (continued)

- Effects
  - Limited agricultural productivity
  - Industrial and extractive activities limited to water access
  - Sparse human settlements
  - Subsistence agricultural economy
- Responses
  - Land reclamation: irrigation
  - Sequence of land conversions
  - Water diversions, impoundments, conveyances

Desertification

- Characteristics
  - Mining of groundwater
  - Loss of riparian systems
  - Loss of soil nutrients
  - Damaged soil surface and subsurface: maximized land uses
  - Increased flash flooding and runoff
  - Deterioration and/or loss of carrying capacity
- Effects
  - Water and wind erosion
  - Salinization of soils
  - Crusting and/or compaction of soils
  - Water salinity buildup
  - Brush invasion
  - Aquifer depletion: subsidence
  - Microclimate changes: deteriorated air quality
  - Altered social structures
  - Changing economic base
  - Loss of farm and rangeland
- Responses
  - Land rehabilitation measures
  - Land use policy: optimized vs. maximized use
  - Innovative management and technological procedures
  - Conservation measures

Source: Evan Vlachos and L. Douglas James, "Drought Impacts," in Vujica Yevjevich, Luis da Cunha, and Evan Vlachos, eds., *Coping with Droughts* (Littleton, CO: Water Resources Publications, 1983), 48.

In many ways, drought is unique among natural phenomena in both cause and effect.[6] Conceptually, sudden natural disasters are extreme events, while droughts are extreme "non-events"--the non-occurrence of water. Floods, earthquakes, and tornadoes begin and end suddenly, and their impact is confined to a local area. Droughts, by contrast, are both creeping and pervasive; they begin slowly, have a long duration, and may affect areas as large as entire continents. They are caused by nature and, essentially, cured by nature when the rains come. This makes them extremely difficult to quantify. Whereas sudden disasters often take an immediate toll in both human lives and structural damage, the consequences of drought are less dramatic, with the exception of famine in some parts of the world.

Thus, drought's effects accumulate with time and, in countries like the United States, are essentially "woven into the economic and social fabric" of a region or the nation.[7] Indeed, drought and the fear of drought also are part of a nation's cultural heritage.[8] According to Tannehill:

> Drought belongs in that class of phenomena which are popularly known as "spells of weather." A drought is a spell of dry weather. Other phenomena in the same general class are: "Indian Summer," the "January Thaw," and those spells of cold, rainy, and other unusual conditions, some of which are supposed to follow certain indications of anniversary dates such as "Groundhog Day" and "St. Swithin's Day." These spells of weather last for an indefinite time, usually between a few days and a few weeks. They are in a different class from the phenomena charted on the daily weather map or the regular seasonal changes of the weather. Most of these spells of weather are associated with elements of superstition or popular misconception.[9]

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[6] Richard A. Warrick, *Drought Hazard in the United States: A Research Assessment* (Boulder, CO: Natural Hazards Research and Applications Information Center, University of Colorado, 1975), 3; and L. V. da Cunha, E. Vlachos, and V. Yevjevich, "Drought, Environment and Society," in Yevjevich, da Cunha, and Vlachos, eds., *Coping with Droughts*, 8.

[7] Warrick, *Drought Hazard in the United States*, 3.

[8] Robert W. Harrison, "Water Supply and Water Quality Studies in the Institute for Water Resources U.S. Army Corps of Engineers," in James E. Crews and James Tang, eds., *Selected Works in Water Supply, Water Conservation and Water Quality Planning* (Fort Belvoir, VA: Institute for Water Resources, U.S. Army Corps of Engineers, 1981), 34. According to Harrison, "Drought needs just as careful study as flood."

[9] Tannehill, *Drought*, vii.

Despite the role of drought in culture and history, people and societies often find it difficult to adapt to or accept drought conditions. The American Water Works Association refers to drought as "an assault on a community" in which there are no winners.[10] Although most of us "know a drought when we see one," the nature of drought also makes it difficult to define and measure with precision.

Defining Drought

Water may be scarce but definitions of drought are not, in part because of the interdisciplinary nature of the phenomenon. Few definitions, however, encompass all of drought's dimensions. M. A. Beran and J. A. Rodier make the following observation:

> It is tempting to search for simple statements such as are found in dictionaries which encapsulate the idea of a drought. This is hardly possible because hydrological observations that are made--rain depth or river flow relative to their average--are far from constant in time and are not synchronous one with one another. The drought of one year or season does not equally and simultaneously affect all the points of the globe, not even a continent.[11]

There are several distinct problems associated with the definition and measurement of drought. One is that the onset of a drought cannot be known with any degree of precision. Even retrospectively, pinpointing the beginning of a drought is difficult. Concurrently, it is virtually impossible. Drought conditions do not begin at the end of the last rainfall, but sometime thereafter. In fact, the onset of a drought, however ominous it later becomes, is actually the onset of desirable weather as far as most people are concerned. As Tannehill remarks:

> We may say truthfully that we scarcely know a drought when we see one. We welcome the first clear day after a rainy

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[10] American Water Works Association, *Before the Well Runs Dry: Volume II--A Handbook on Drought Management* (Denver, CO: American Water Works Association, 1984), 6.

[11] M. A. Beran and J. A. Rodier, *Hydrological Aspects of Drought* (Paris: UNESCO and the World Meteorological Organization, 1985), 2.

> spell. Rainless days continue for a time and we are pleased to have a long spell of such fine weather. It keeps on and we are a little worried. A few days more and we are really in trouble. The first rainless day in a spell of fine weather contributes as much to the drought as the last, but no one knows precisely how serious it will be until the last dry day is gone and the rains have come again. We ask if this was just a chance combination of dry days, or were we, even from the first, in the grip of some powerful force which might have been recognized?[12]

Although droughts always end, even the conclusion of a drought is difficult to measure. One day's rainfall is often insufficient to remedy drought conditions. And again, retrospective measurement of the end of a drought is hard enough; concurrent measurement is nearly impossible. A related problem with drought measurement is the fact that historical patterns reveal that regions can slip into and out of drought conditions. During the upswing or downswing of a drought cycle, it is never easy to say with certainty that a new pattern is being established. A day's rainfall may signal a short reprieve or an actual rescue from the drought.

Given these problems of conceptualization, it is not surprising that some definitions are distinctly vague, as illustrated by the following examples of meteorological definitions of drought:[13]

- A period of more than some particular number of days with precipitation less than some specified amount.
- A temporary departure from the average climate toward drier conditions.
- A period of monthly or annual precipitation less than some particular percentage of normal.
- A sustained period of time without significant rainfall.
- A deficit of water below a given reference value, with both deficit duration and deficit magnitude taken into account.

Drought definitions become more precise when attached to specific water purposes (such as agricultural needs) or hydrological conditions (such as streamflows). Some analysts also allow for the possibility of different types of drought, each calling for a distinct definition. A study by UNESCO and the World Meteorological Organization emphasizes that, "it is not drought itself which is strictly defined by important attributes or characteristics."[14] Thus the report identifies six different types of drought:

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[12] Tannehill, *Drought*, 15.

[13] Ibid.

- A three-week to three-month runoff deficit during the period of germination and plant growth. This could be catastrophic for farming that is dependent upon irrigation drawn directly from the river without the support of reservoirs.
- A minimum discharge significantly lower or more prolonged than the normal minimum but not necessarily advanced much in its position relative to the growing season. Because the germination period is not affected this type of drought is of less consequence to agriculture.
- A significant deficit in the total annual runoff. This affects hydropower production and irrigation from large reservoirs.
- A below normal annual high water level of the river. This may introduce the need for pumping for irrigation. This type of drought is related to the third type--deficit in annual runoff.
- Drought extending over several consecutive years as with the "Secas" of Northeast Brazil. Discharge remains below a low threshold or the rivers dry up entirely and remain dry for a very long time.
- A significant natural depletion of aquifers. This is difficult to quantify because observation of the true level of the aquifer is disturbed by the overutilization of groundwater during the drought.

According to a framework advanced by Donald A. Wilhite and Michael H. Glantz, drought definitions fall into four general categories: meteorological, agricultural, hydrological, and socioeconomic.[15] Some of the definitions of drought developed by analysts over the years are organized according to this categorization and summarized in table 4-2.

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[14] Beran and Rodier, *Hydrological Aspects of Drought*, 3-4.

[15] Donald A. Wilhite and Michael H. Glantz, "Understanding the Drought Phenomenon: The Role of Definitions," in Donald A. Wilhite and William E. Easterling, eds., *Planning for Drought: Toward a Reduction of Societal Vulnerability* (Boulder, CO: Westview Press, 1987), 14.

TABLE 4-2

DROUGHT DEFINITIONS

Author	Year	Definition
Meteorological Drought		
Condra	1944	A "period of strong wind, low precipitation, high temperature and, usually, low relative humidity." This definition applied specifically to drought conditions in the Great Plains area.
Levitt	1958	Expressed atmospheric drought as proportional to the vapor pressure deficit of the air.
Linsley, et al.	1958	A "sustained period of time without significant rainfall."
Downer, et al.	1967	A "deficit of water below a given reference value, with both deficit duration and deficit magnitude taken into account."
McGuire & Palmer	1957	A "period of monthly or annual precipitation less than some particular percentage of normal."
Palmer	1957	A temporary departure from the average climate toward drier conditions.
Palmer	1965	Developed the Palmer Drought Severity Index, which relates the severity of a drought to the accumulated weighted differences between actual precipitation and the precipitation requirement of evapotranspiration.
Gibbs & Maher	1967	Developed a drought measurement system by ranking monthly and annual precipitation totals and determining decile ranges from the cumulative frequency of the distribution, i.e., the first decile represents the precipitation values in the lowest ten percent of the distribution.
Lee	1979	Developed the Australian Drought Watch System, which uses deciles of precipitation to determine when droughts are developing. A severe drought is defined as a dry period not exceeding the fifth decile range over a period of three or more months.
Changnon	1980	Measured drought by comparing the amount of departure of precipitation from normal to the impact of the weather on the economy.

TABLE 4-2--Continued

Author	Year	Definition
Agricultural Definitions		
Barger	1949	Linked the severity of drought to impacts on corn crops.
Kulik	1958	Determined drought intensity by measuring the difference between plant water demand and available soil water.
Palmer	1968	Developed the Crop Moisture Index, which determines the severity of a drought based on the magnitude of the abnormal evapotranspiration deficit.
Hydrologic Definitions		
Linsley, et al.	1975	A period in which "streamflows are inadequate to supply established uses under a given water management system."
Whipple	1966	Defined a drought year as one in which the aggregate runoff is less than the long-term average runoff.
Dexman, et al.	1982	Developed the Surface Water Supply Index, which uses historical data and current figures of reservoir storage, streamflow, and precipitation at high elevation, etc., to form a single index number.
Socioeconomic Definitions		
Hoyt	1936 and 1942	"When precipitation is not sufficient to meet the needs of established human activities." also, droughts may occur when "in the economic development of a region man creates a demand for more water than is normally available."
Heathcote	1974	A "shortage of water harmful to man's agricultural activities. It occurs as an interaction between agricultural activity (i.e., demand) and natural events (i.e., supply), which results in a water volume or quality inadequate for plant and/or animal needs."
Gibbs	1975	Amplified on Heathcote by defining demand as "dependent upon the distribution of plant, animal and human populations, their lifestyle and their use of the land."
Sandford	1979	Linked drought not only to precipitation but also to other factors that influence supply and to trends or fluctuations in demand.

Source: Authors' construct from Donald A. Wilhite and Michael H. Glantz, "Understanding the Drought Phenomenon: The Role of Definitions," in Donald A. Wilhite and William E. Easterling, eds., *Planning for Drought: Toward a Reduction of Societal Vulnerability* (Boulder, CO: Westview Press, 1987), 15-19.

Meteorological definitions are weather-based, focusing on the degree of dryness and the duration of dry periods. Agricultural definitions link meterological conditions to agricultural impacts, often with reference to the evapotranspiration cycle. Hydrological definitions emphasize depletions in water levels and use streamflow data over time. Finally, socioeconomic definitions may incorporate any of the other drought definitions while emphasizing effects on the supply and demand for an economic good. A classic, although vague, definition of drought from the socioeconomic perspective was advanced by J. C. Hoyt in 1936: "when precipitation is not sufficient to meet the needs of established human activities." Hoyt also suggested, in 1942, that mankind can bring drought upon itself when economic development creates more demand for water than normal supplies can meet.[16]

Measuring Drought

If defining drought is difficult because of its temporal and spatial features, measuring drought is even more so. Drought has been measured differently around the world. Wilhite and Glantz provide the following examples of meteorological measurements of drought:[17]

- Less than 2.5 mm of rainfall in forty-eight hours (United States, 1942).
- Fifteen days, none of which received as much as 0.25 mm of rainfall (Britain, 1936).
- When annual rainfall is less than 180 mm (Libya, 1964).
- Actual seasonal rainfall is deficient by more than twice the mean deviation (India, 1960).
- A period of six days without rain (Bali, 1964).

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[16] J. C. Hoyt (1936 and 1942) as reported in Wilhite and Glantz, "Understanding the Drought Phenomenon," ibid., 18.

[17] Ibid.

The conventional measure of meteorological drought in the United States and many parts of the world is the Palmer Drought Index (PDI).[18] The label is somewhat of a misnomer because the index applies to prolonged *wet* periods as well as prolonged *dry* periods. The index uses historical records based on the idea of a hydrologic accounting system that defines a region's moisture characteristics. Constants are developed for five indicators: evaporation, recharge, runoff, moisture loss, and precipitation. The index relates drought severity to the accumulated weighted differences between actual precipitation and the precipitation required for evapotranspiration.

According to the U.S. Department of Agriculture (USDA), the index can be used to measure the disruptive effects of prolonged dryness or wetness, designate disaster areas, and reflect the general, *long-term* status of water supplies in aquifers, reservoirs, and streams.[19] As such, PDI values change little from week to week.[20]

As depicted in table 4-3, Palmer index values are positive for wet conditions and range from 0 to 4.00 or more. Index values are negative for dry conditions and range from 0 to -5.00 or less. Normal conditions for any particular region hover around 0. Progressively drier conditions call for progressively more serious responses. Alert and warning stages activate monitoring and appraisal of conditions.[21] A PDI of -4.00 or less constitutes an extreme drought that warrants an emergency response; when it reaches -5.00 or less, conditions are considered disastrous. Hundreds of PDI values are calculated for small areas across the nation and published in alternating issues of the USDA *Weekly Weather and Crop Bulletin*.[22]

In some cases, other measures are used in conjunction with the Palmer Drought Index. A study by UNESCO and the World Meterological Organization

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[18] Prasifka, *Current Trends in Water-Supply Planning*, 217; and Wilhite and Glantz, "Understanding the Drought Phenomenon," in Wilhite and Easterling, eds., *Planning for Drought*, 15.

[19] U.S. Department of Agriculture, *Week Weather and Crop Bulletin*.

[20] An alternative measure, the Crop Moisture Index, can be used to assess the short-term effects of dryness and wetness on crops and field operations.

[21] U.S. Army Corps of Engineers and Pennsylvania Bureau of Water Resources Management, *The State of the States in Water Supply/Conservation Planning and Management Program* (Fort Belvoir, VA: Institute for Water Resources, U.S. Army Corps of Engineers, 1983), B-25.

[22] Two drought severity maps based on the PDI are reproduced in chapter 5.

TABLE 4-3

THE PALMER DROUGHT SEVERITY INDEX

Direction	Palmer Index	Condition	Response
↑	4.00 or more	Extremely wet	-
↑	3.00 to 3.99	Very wet	-
↑	2.00 to 2.99	Moderately wet	-
↑	1.00 to 1.99	Slightly wet	-
↑	.50 to 0.99	Incipient wet	-
	0.49 to -0.49	Normal	Normal
↓	-0.50 to -0.99	Incipient drought	Normal
↓	-1.00 to -1.99	Mild drought	Alert
↓	-2.00 to -2.99	Moderate drought	Alert
↓	-3.00 to -3.99	Severe Drought	Warning
↓	-4.00 or less	Extreme drought	Emergency
↓	-5.00 or less	Extreme drought	Disaster

Source: Adapted from U.S. Army Corps of Engineers and Pennsylvania Bureau of Water Resources Management, *The State of the States in Water Supply/Conservation Planning and Management Programs* (Fort Belvoir, VA: Institute for Water Resources, U.S. Army Corps of Engineers, 1983), and numerous renditions.

reports a drought index that measures the proportion of studied rivers experiencing conditions drier or wetter than the five-year return period level.[23] In its 1982 Drought Preparedness Plan, the state of New York set forth an index based on measures of precipitation, reservoir and lake storage, streamflow, and groundwater level, as summarized in table 4-4.[24] For each indicator, values are weighted according to six regions in the state. The result is an index with values ranging from 0 to 150, with lower

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[23] Beran and Rodier, *Hydrological Aspects of Drought*. A hydrograph of values using this method appears in figure 5-1 of this report.

[24] See also, Margaret S. Hrezo, Phyllis G. Bridgeman, and William R. Walker, "Managing Droughts Through Triggering Mechanisms," *American Water Works Association Journal* 78, no. 6 (June 1986): 46-51.

TABLE 4-4

NEW YORK'S DROUGHT INDICATORS

- Precipitation
  - Cumulative departure over a time period

- Reservoir/Lake Storage
  - Current storage as a percent of usable capacity compared with historic or normal storage
  - Number of days of water supply remaining
  - Inches of rain required to fill a reservoir

- Streamflow
  - Base flow from discharges of groundwater
  - Surface runoff resulting from precipitation

- Groundwater Levels
  - Comparison of conditions to long-term records using observation wells in uplands and basin floors that monitor shifts in underground aquifers

Source: Adapted from David W. Prasifka, *Current Trends in Water Supply Planning* (New York: Van Nostrand Reinhold and Co., 1988), 218.

values indicating dry conditions. The index corresponds to the Palmer index so that, for example, 50 to 75 points on the New York index and -3.00 to -3.99 on the PDI both indicate the warning stage.

Another alternative to the Palmer index was developed recently by James Hansen and colleagues as part of a study of regional greenhouse climate effects.[25] It is simpler and more general than the PDI because it requires fewer locally defined parameters. It also addresses meteorological, hydrological, and agricultural aspects of drought. The drought index, D, is a measure of the differences between atmospheric supply of moisture and atmospheric demand for moisture:

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[25] The testimony incorporates J. Hansen, et al., "Regional Greenhouse Climate Effects," in *Proceedings of the Second North American Conference on Preparing for Climate Change, December 6-8 1988* (Washington, DC: Climate Institute, 1989).

$$D\ (\text{current month}) = 0.9\ D\ (\text{previous month}) + d/\sigma$$

where:

$$d = (\text{precipitation} - \text{potential evaporation})_{\text{actual}}$$

$$-(\text{precipitation} - \text{potential evaporation})_{\text{climatology}}$$

σ = standard deviation of d

As the authors explain, the ratio d/σ is a dimensionless measure of the precipitation deficit (negative) or excess (positive) in the current month. The index includes a memory of deficits or excesses of preceding months. Because the index continues to yield negative values after evaporation ceases because of lack of available water, it provides an indicator of stress on vegetation. It also measures reservoir water balance because there is normally water available for evaporation from reservoirs. When compared with PDI values, the index D-proves to be another valid measure of drought. Thus the Hansen index is a measure that may gain in usage.

Predicting Drought

Based on extensive research on drought, Tannehill concluded that:

> In the future, farmers will not have to gaze despairingly into a clear sky, wondering if a few clear days will continue into a disastrous drought. Even if we are never able to control the climate, much will be gained by knowing what to expect. Droughts are not mere chance occurrences; they are part of a physical process which can be measured and studied and predicted with increasing precision as our observations of the sun and the upper air and the oceans continue to accumulate.[26]

Drought prediction depends largely on one's discipline and perspective within that discipline. According to Tannehill, one school of thought views climate as simply average weather:

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[26] Tannehill, *Drought*, 231.

> If we take the classical view, we start with the assumption that a rainless day is a more or less independent incident in the run of weather. Two consecutive rainless days constitute a coincidence. Three rainless days make a chance combination. If this keeps up, we have a drought. The frequency of certain combinations of rainless days is a feature of the climate of a place. There is a certain expectation of drought based on past records of rainy and rainless days. We do not assign the cause of the drought but we can explain each rainless day, and the sum total of these individual explanations must serve as the explanation of the drought.[27]

Another school of thought contends that climate is as variable as the weather. This perspective is behind most attempts at defining or explaining the occurrence of drought as well as drought prediction and broad-scale changes in global climate. Assuming that climatic episodes occur in nonrandom fashion, prediction is conceptually possible.

Precise forecasting of drought occurrences is extremely difficult. Many scientists turn instead to estimating the *probability* of drought.[28] Drought probabilities can be estimated based on historical cycles.[29] Having a rough idea of drought probabilities for a region facilitates planning for both agricultural and urban water uses, thereby reducing uncertainty and mitigating the impact of droughts when they do occur.

Predictive accuracy, of course, depends on a record of historic accuracy for the advocated method, which in turn depends on the validity and reliability of the variables used to estimate drought probabilities. Some have proposed the use of palaeoenvironmental or geomorphological indicators, such as tree rings, to measure the historical occurrence of drought.[30] Others look skyward to atmospheric conditions, such as sunspots and meteor dust.[31] Still others look to the ocean for explanatory variables.[32]

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[27] Ibid., 7.

[28] Warrick, *Drought Hazard in the United States*, 13.

[29] Some of these studies are summarized by Warrick in *Drought Hazard in the United States*, 13-15.

[30] Larry J. Puckett, *Dendroclimatic Estimates of a Drought Index for Northern Virginia* (Washington, DC: U.S. Geological Survey, 1981).

[31] George N. Newhall, *Sunspots, Dust, and Rainfall* (Davis, CA: S&G Publishers, 1988). According to the book's cover page, "The Sun Drives the Climate Machine."

[32] Tannehill, *Drought*.

Some drought forecasting approaches are very sophisticated. According to the UNESCO and the World Meteorological Organization, drought forecasting methodologies can be classified as either meteorological or hydrological.[33] Meteorological methods apply statistical, physical, or synoptic techniques to weather data. Included are analogue methods, linear regression equations, teleconnections, statistical and kinematic methods, contingency tables, use of air-sea interactions, statistical time-series forecasts, and extrapolation in time using cyclicities. Hydrological methods are generally applicable after the onset of a drought and make use of data on river flows and aquifers. Included in this approach are recession-based methods, regression methods, and cycles in annual streamflow. Scientists also continue to struggle with the question of whether droughts are generally periodic or cyclical in nature.

Some of these drought-prediction methods correspond to the water supply forecasting techniques described briefly in chapter 2 and reviewed by the U.S. Army Corps of Engineers.[34] These include the Basin Climatic Index Method, the National Weather Service River Forecasting System, the Snow Accumulation and Ablation Model, the Sacramento Soil Moisture Accounting Model, and the Stochastic Conceptual Hydrologic Model.

Early warning is an important part of drought prediction and analysis. Since 1979, the Assessment and Information Services Center (AISC) of the National Oceanic and Atmospheric Administration/National Environmental Satellite, Data and Information Service (NOAA/NESDIS) has provided climate impact analysis, including early warning alerts about drought, to national and international agencies that use this information in conducting agricultural assessments and planning relief efforts.[35] The system uses agroclimatic indices, satellite assessment models and crop yield forecasts to provide information on the potential impact of weather variability on food crops for more than eighty countries throughout the tropic regions of the world (Africa, Asia, Latin America, and the Southwest Pacific Basin). Agencies using the system include the U.S. Agency for International Development, the Department of State, the Department of Agriculture, the Central Intelligence Agency, United States missions abroad, and agencies of the United Nations. A major part of the AISC system is the provision of technical assistance to developing nations so that they might implement their own drought early warning systems.

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[33] Beran and Rodier, *Hydrological Aspects of Drought*, 55-59.

[34] Benedykt Dziegielewski, Duane D. Baumann, and John J. Boland, *The Evaluation of Drought Management Measures for Municipal and Industrial Water Supply* (Fort Belvoir, VA: Institute for Water Resources, U.S. Army Corps of Engineers, 1983).

[35] Clarence M. Sakamoto and Louis T. Steyaert, "International Drought Early Warning Program of NOAA/NESDIS/AISC," in Wilhite and Easterling, eds., *Planning for Drought*, 247-72.

The interest in drought prediction has increased with interest in the subject of global warming generally, as discussed in chapter 2. Some analysts predict that global warming will cause droughts to occur with more frequency and intensity. James E. Hansen of the National Aeronautics and Space Administration's Goddard Institute for Space Studies (and his colleagues) recently provided rather dramatic dryness and drought predictions through the year 2060, as reported in figure 4-2.[36] The authors explain that under conditions of global warming, higher surface air temperatures would lead to more evaporation and, thus, to more dryness and drought.

Despite methodological advances, drought prediction is fraught with frustration; in fact, the probability of predictive accuracy is only slightly better than chance (a 50 percent probability of accuracy). Long-run temperature forecasts in the United States are about 65 percent accurate; precipitation forecasts are about 60 percent accurate. Apparently, drought forecasting accuracy has not been verified, but is expected to be about 60 percent as well.[37]

Another approach to drought prediction is to accept the inevitability of drought and predict its recurrence with more certainty.[38] At least one major drought strikes the continental United States every decade.[39] The occurrence of two, as in the early and late 1980s, is not uncommon.

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[36] J. Hansen, et al., "Regional Greenhouse Climate Effects," in *Proceedings of the Second North American Conference on Preparing for Climate Change.*

[37] Beran and Rodier, *Hydrological Aspects of Drought*, 59.

[38] This point is also made by Dean Mann, "Institutional Arrangements by the State, Regional, and National Levels," in Gary D. Weatherford, ed., *Water and Agriculture in the Western U.S.: Conservation, Reallocation, and Markets* (Boulder, CO.: Westview Press, 1982), 45.

[39] Tannehill, *Drought*, 161-62.

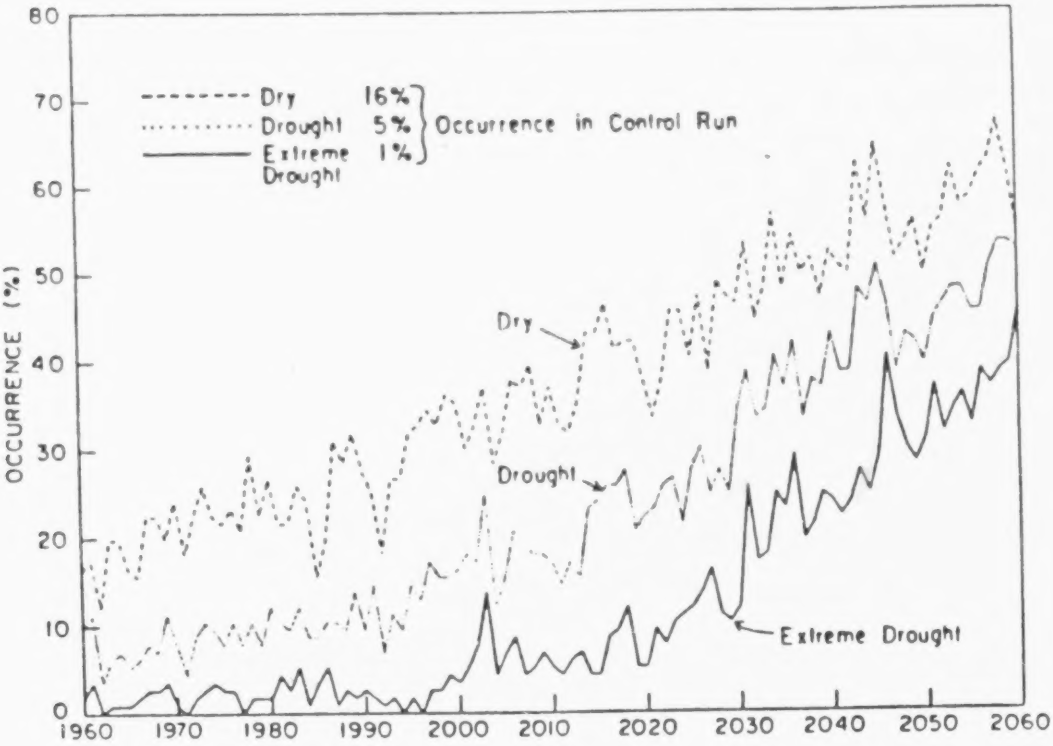

Fig. 4-2. Future droughts in a global warming scenario as depicted in J. Hansen, et al., "Regional Greenhouse Climate Effects," in *Proceedings of the Second North American Conference on Preparing for Climate Change, December 6-8 1988* (Washington, DC: Climate Institute, 1989).

There is no doubt that drought prediction has its place in scientific inquiry. However, the accuracy of prediction, even if vastly improved, will always be imperfect. Thus, the margin of error, at least in the foreseeable future, appears to be great enough to justify a risk-management approach.

Consequences of Drought

Perceptions of droughts and their consequences differ markedly. As Wilhite and Easterling explain, meteorologists and sociologists, for example, view drought as "quite different problems--the former striving to predict or explain the physical causes of drought or describe the magnitude of the precipitation deficiency while the latter is more interested in the effects of the deficiency on people and their institutions."[40]

A systems approach to drought is depicted in figure 4-3, which illustrates the linkages between physical and social factors. As Wilhite and Glantz explain:

> Drought events are shown as inputs to a physical-environment system and a social system. The characteristics of drought events, physical-environment systems, and social systems combine and interact to produce impacts on the physical-environment and social system. The social system responds to mitigate or alleviate drought-related impacts. This view of drought reflects the focus of previous studies of drought on the physical aspects of the phenomenon. Yet the ultimate significance of drought to society lies in its impacts.[41]

The effects of drought can be assessed for different systems within society and at different levels, as portrayed in figure 4-4.[42] Drought and the perception of drought affect management practices in the agricultural system, pricing and other government policymaking in the economic system, and farm vulnerability in the social system. Initial impacts, such as agricultural yields and farm income, are at the local level. These in turn

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[40] Wilhite and Easterling, eds., *Planning for Drought*, preface.

[41] Wilhite and Glantz, "Understanding the Drought Phenomenon," in Wilhite and Easterling, eds., *Planning for Drought*, 19.

[42] Warrick and Bowden (1981) as reported in Martin L. Parry and Timothy R. Carter, "Climate Impact Assessment: A Review of Some Approaches," in Wilhite and Easterling, eds., *Planning for Drought*, 168.

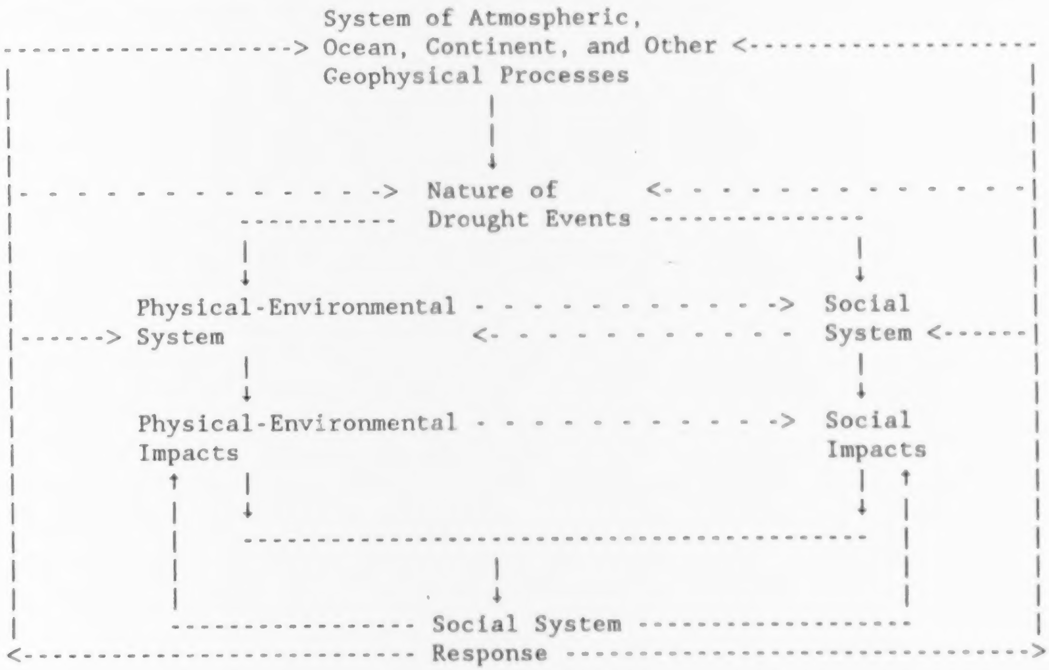
System of Atmospheric, Ocean, Continent, and Other Geophysical Processes
Nature of Drought Events
Physical-Environmental System
Social System
Physical-Environmental Impacts
Social Impacts
Social System Response

Fig. 4-3. Drought viewed in a system context as depicted by W. J. Gibbs and reported in Donald A. Wilhite and Michael H. Glantz, "Understanding the Drought Phenomenon: The Role of Definitions," in Donald A. Wilhite and William E. Easterling, eds., *Planning for Drought: Toward a Reduction of Societal Vulnerability* (Boulder, CO: Westview Press, 1987), 20.

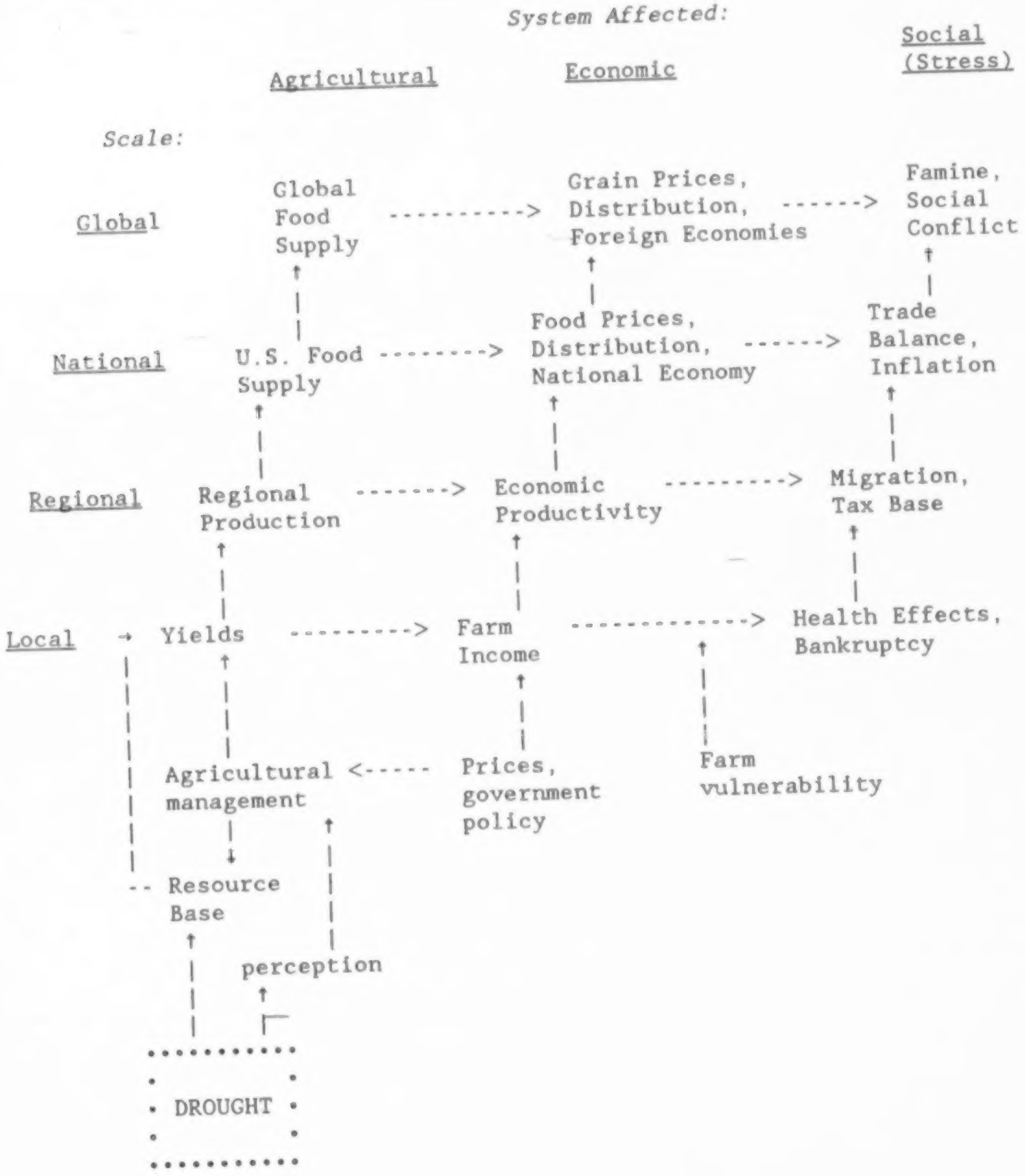
System Affected:
Agricultural
Economic
Social (Stress)
Scale:
Global
Global Food Supply
Grain Prices, Distribution, Foreign Economies
Famine, Social Conflict
National
U.S. Food Supply
Food Prices, Distribution, National Economy
Trade Balance, Inflation
Regional
Regional Production
Economic Productivity
Migration, Tax Base
Local
Yields
Farm Income
Health Effects, Bankruptcy
Agricultural management
Prices, government policy
Farm vulnerability
Resource Base
perception
DROUGHT

Fig. 4-4. Global implications of drought as depicted by Warrick and Bowden (1981) and reported in Martin L. Parry and Timothy R. Carter, "Climate Impact Assessment: A Review of Some Approaches," in Donald A. Wilhite and William E. Easterling, eds., *Planning for Drought: Toward a Reduction of Societal Vulnerability* (Boulder, CO: Westview Press, 1987), 168.

may contribute to regional effects on productivity and the tax base. At the national level, drought can affect food supplies, prices, and even the trade balance and inflation. Finally, drought has global effects that reach the economies of foreign governments and, in the social system, can create stress through famine and related social conflict. As noted earlier, drought has been viewed by some observers as inseparable from famine, war, and disease since Biblical times.

A categorization of drought effects was developed by the Western Governors' Policy Office in 1977 as represented in table 4-5.[43] It distinguishes among economic impacts, environmental impacts, social impacts, and constraints to the implementation of drought mitigation measures. The effects of drought on the economic sector are far-reaching and not confined to agricultural losses. Drought has an adverse economic impact, for example, on recreational business. Some impacts are secondary, such as economic losses to industries affected by drought-related power curtailments or reductions in agricultural production. Economic impacts on water supply firms may be negative (revenue shortfalls) or positive (windfall profits). Environmental effects include adverse impacts on animal and plant species as well as air and water quality. Social impacts include public safety and health as well as an array of potential lifestyle changes. Finally, there are numerous financial, institutional, and practical constraints to drought mitigation measures.[44]

The consequences of drought include adjustment by many sectors of society. An important consequence is that drought affects planning and management not only in the water supply sector but in other sectors as well. Adjustments to real or potential water shortages can be identified in each of the principal water use categories.[45] In the domestic and commercial sector, plumbing fixtures have become more water efficient, and some state and local governments have required their installation. In the agricultural sector, improvements in irrigation efficiency have been made. In the

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[43] Western Governors' Policy Office (WESTPO), 1977, as reported in Wilhite and Glantz, "Understanding the Drought Phenomenon," in Wilhite and Easterling, eds., *Planning for Drought*, 22-23.

[44] On drought mitigation, see chapter 6.

[45] Many of these adjustments are considered later in this report.

TABLE 4-5

IDENTIFICATION AND CLASSIFICATION OF DROUGHT-RELATED PROBLEMS

Classification/ Problems and Impacts	Affected Sectors*
Economic Impacts	
• Economic loss from drought-impacted dairy and beef production	A
- impaired productivity of rangeland	A
- forced reduction of foundation stock	A
- closure/limitation of public lands to grazing	A
- high-cost/unavailability of water for cattle	A
- high-cost/unavailability of feed for cattle	A
- increased predation	A
- range fires	A,M,S
• Economic loss from drought-impacted crop production	A
- damage to perennial crops; crop loss	A
- impaired productivity of cropland (wind erosion, etc.)	A
- insect infestation	A
- plant disease	A,S
- wildlife damage to crops	A
• Economic loss from drought-impacted timber production	B
- forest fires	B
- tree disease	B,S
- insect infestation	B,S
- impaired productivity of forest land	B,S
• Economic loss from drought-impacted fishery production	A,S
- damage to fish habitat	H,S
- insufficient flows for anadromous and catadromous fish	H,S
- loss of young fish due to decreased flows	H,S
• Economic loss from drought-impacted recreational businesses	B,M,S
• Economic loss to manufacturers and sellers of recreational equipment	B,M,S
• Economic loss to industries impacted by drought-related power curtailments	B,M,S
• Economic loss to industries directly dependent on agricultural production (e.g., fertilizer manufacturers, food processors)	B,M,S
• Unemployment from drought-related production declines	H,B,S
• Strain on financial institutions	S,A
• Revenue losses to state and local governments	S,M
• Revenues to water supply firms	M
- revenue shortfalls	M
- windfall profits	M

TABLE 4-5--Continued

Classification/ Problems and Impacts	Affected Sectors*
Economic Impacts (cont.)	
• Economic loss from impaired navigability of streams, rivers, and canals.	B
• Cost of water transport or transfer	H,A,B,M,S
• Cost of new or supplemental water source development	H,A,B,M,S
Environmental Impacts	
• Damage to animal species	A,S
- damage to wildlife habitat	S,H
- lack of feed and drinking water	A,H
- disease	A,S
- vulnerability to predation	A
• Damage to fish species	S
• Damage to plant species	S
• Water quality effects (e.g., salt concentration)	A,M
• Air quality effects (dust, pollutants)	H,S
• Visual and landscape quality (dust, vegetation cover, etc.)	H,S
Social Impacts	
• Public safety from forest and range fires	M,S
• Health-related low flow problems (e.g., diminished sewage flows, increased pollutant concentrations, etc.)	M,S
• Inequality in the distribution of drought impacts/relief	A,H,B,M,S
• Lifestyle impacts	
- unemployment	H,A,S
- loss of ownership	A
- loss of savings	H,A
- retirement	H
- small family farming	A
- uncertainty	H,A,B,M,S
- recreation	H,B,M,S
- personal hygiene	H
- dirty cars and streets	H
- water reuse in home	H
- entertaining	H,B
Constraints to Implementation of Drought Mitigation Measures	
• Legal/institution constraints	M,S
- to water conservation/efficiency measures	M,S,A
- to water supply augmentation measures	M,S,A
• Financial constraints	H,A,B,M,S
- to water conservation/efficiency measures	A,B,M,S
- to water supply augmentation measures	A,B,M

TABLE 4-5--Continued

Classification/ Problems and Impacts	Affected Sectors*
Constraints (cont.)	
• Inadequate drought management capability/authority - local, state, federal	M
• Inadequate understanding of drought problems and mitigation measures; public apathy	M,S
• Shortages of needed parts, equipment, manpower	A,M

Source: Adaptation by the Western Governors' Policy Office (WESTPO), 1977, as reported in Donald A. Wilhite and Michael H. Glantz, "Understanding the Drought Phenomenon: The Role of Definitions," in Donald A. Wilhite and William E. Easterling, eds., *Planning for Drought: Toward a Reduction of Societal Vulnerability* (Boulder, CO: Westview Press, 1987), 22-23.

* Key:
M = Municipalities
S = State governments
B = Businesses and industries
A = Agricultural enterprises
H = Households and individuals

industrial sector, water recycling in many manufacturing processes is on the rise. Finally, the energy development sector has explored recycling as well as other technologies to reduce the amount of water used in cooling. In most cases, these adjustments make sense from the perspective of economic efficiency as well as water efficiency.

Using rough but quantified indicators (such as irrigated acreage), Richard A. Warrick linked a variety of adjustments in the agricultural sector to the historical occurrence of droughts in the 1930s and 1950s, as depicted in figure 4-5.[46] Droughts of the 1930s were linked to increased adoption of relief and rehabilitation, cultivation practices, financial protection, irrigation, operational flexibility, and land-use regulation. Droughts of the 1950s were followed by continued changes in these areas, plus new

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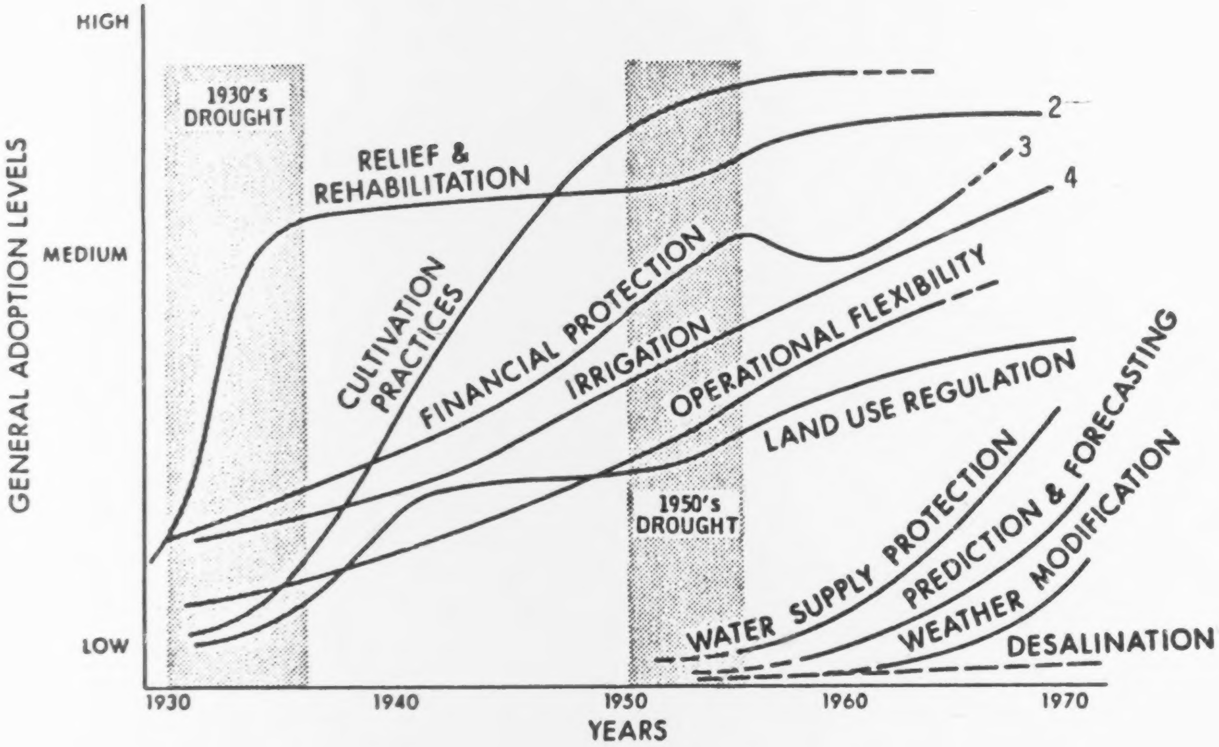
[46] Warrick, *Drought Hazard in the United States*.



1. Very rough approximation of relative levels of adoption.
2. Institutional arrangements for R&R--not payments.
3. Shape of curve generalized from number of acres insured and amounts of loans in the United States (dip in 1950's reflects lower adoption of insurance at that time).
4. Based on total irrigated acres in the United States.

Fig. 4-5. Generalized historical trends of drought adjustment as depicted in Richard A. Warrick, *Drought Hazard in the United States: A Research Assessment* (Boulder, CO: Natural Hazards Research and Applications Information Center, University of Colorado, 1975).

attention in the areas of water supply protection, prediction and forecasting, weather modification, and desalination. Droughts of the 1980s may result in another set of institutional trends. Chief among these may be planning, conservation, technological solutions, and water reuse.

The effects of drought on electric power production are summarized in table 4-6. Of course, many steam electric generation facilities are largely unaffected by drought. These include facilities located on large freshwater lakes and the lower reaches of major rivers, those located on the coasts that use seawater for cooling, and those that rely on deep groundwater sources for makeup water (such as plants in Texas and the Southwest).[47] Hydroelectric power poses a different situation, as explained in a report of the Electric Power Research Institute (EPRI):

> Drought has its most severe and direct impacts on the generation of hydroelectric power. The effects of drought on hydropower generation are essentially universal and must be considered in the rating of firm power generating capability. Because of the large cost differentials between hydroelectric and other forms of energy, shortfalls in hydroelectric production can have substantial economic effects. Minor improvements in flow forecasting or in the operation of hydroelectric facilities can result in great cost savings.[48]

Concern about drought already pervades the design, regulation, and operation of electric power facilities. Continued adjustments to drought in the area of thermoelectric power production may include the adoption of technologies that recycle water or use less water altogether, such as dry-cooling systems.[49] In the case of hydroelectric power, improvements in the estimation of drought probabilities are especially essential. According to EPRI, evaluating drought impacts on electricity generation is best accomplished through the use of a computer simulation for assessing the effects of different drought scenarios on plant performance.[50]

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[47] D. P. Lettenmaier, et al., *Strategies for Coping with Drought, Volume 1: Problem Identification*. (Palo Alto, CA: Electric Power Research Institute, 1986), 4-2.

[48] Ibid., 5-1.

[49] Electric Power Research Institute, "Water Water Everywhere But...," *EPRI Journal* 4, no. 8 (October 1979): 6-13.

[50] Lettenmaier, et al., *Strategies for Coping with Drought, Volume 1*, 5-3.

TABLE 4-6

IMPACT OF DROUGHT ON ELECTRIC POWER PRODUCTION

Steam Electric Generation

- Design considerations
  - Difficulties in assessing reliability of cooling-water supplies both in terms of water quantity and the ability to meet water quality objectives.
  - Uncertain loss rate from cooling ponds by evaporation and seepage.

- Regulatory aspects
  - Difficulties in meeting thermal discharge standards.
  - Difficulties in meeting standards for disposal of blowdown waste.
  - Restrictions on withdrawals during periods of low flow including requirements to provide makeup reservoirs to replace consumptive use, or shut down generating units.

- Operational considerations
  - Flow (and stage) forecasting.
  - Water quality forecasting.
  - Optimal operation of hydro/thermal systems during drought.

Hydroelectric Generation

- Estimating drought probabilities.
- Incorporating the probabilistic nature of drought in the planning process.
- Making operational decisions during drought.

Source: Adapted from D. P. Lettenmaier, et al., *Strategies for Coping with Drought, Volume 1* (Palo Alto, CA: Electric Power Research Institute, 1986), 4-4 and 5-1.

Should water become more scarce and the competition for water more intense, the potential consequences of water shortages due to drought or other reasons will become increasingly apparent. Society and its many sectors will also adapt to drought by adjusting water-use practices, many of which are not just emergency measures. As in the case of many changes already made in the agricultural and energy sectors, they can leave a permanent impression.

Observations about Drought

Wilhite and Glantz make ten key observations about drought, drought measurement, and the effects of drought that seem to reflect the core concerns shared by the leading drought analysts:[51]

- The lack of a precise (and objective) definition of drought in a specific situation has been an obstacle to understanding drought, which has led to indecision and/or inaction on the part of managers, policymakers, and others.
- There cannot (and should not) be a universal definition of drought.
- Available definitions demonstrate a multidisciplinary interest in drought.
- It is useful to subdivide definitions of drought into four types on the basis of disciplinary perspective (meteorologic, agricultural, hydrologic, and socioeconomic).
- Drought is a complex phenomenon with pervasive societal ramifications.
- Most scientific research related to drought has emphasized physical rather than societal aspects.
- Drought severity is sometimes expressed by its societal impacts, although the precise nature of those impacts is difficult to quantify.
- Secondary and tertiary effects often extend beyond the spatially defined borders of drought.
- Drought impacts are long-lasting, at times lingering for many years.
- Human or social factors often aggravate the effects of drought.

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[51] Wilhite and Glantz, "Understanding the Drought Phenomenon," in Wilhite and Easterling, eds., *Planning for Drought*, 24.

While drought is a natural phenomenon, mankind can make matters better or worse. The fact that societies have made various adjustments to drought supports the proposition that drought conditions can be managed in the long term. In the short term, however--despite their perennial nature--droughts still seem to take many water suppliers, water users, and even govern-ment agencies by surprise. The 1988 drought, reviewed in the following chapter, is a case in point.

CHAPTER 5

THE 1988 DROUGHT

In 1988, the continental United States experienced drought conditions serious enough to call into question the nation's ability to deal with water shortages. One positive effect of the drought has been to heighten awareness of water supply issues among members of the scientific and governmental communities as well as among the media and the public at large.

Although severe, the 1988 drought was not a unique event. Despite the record high temperatures and record low rainfall experienced by some parts of the country in 1988, the droughts of the 1930s and 1950s were more extreme, and it is likely that other more severe droughts occurred in times before accurate weather records were maintained.[1]

The hydrograph in figure 5-1 provides an historical perspective of drought for the northern prairie states and adjacent parts of Canada, based on an index that reflects the proportion of studied rivers experiencing conditions drier or wetter than the five-year return-period level.[2] Especially noticeable is the drought of the 1930s, constituting the infamous "dustbowl" era. It was the most widespread drought ever recorded in the United States, affecting 61 percent of the country in 1934 and lasting more than a decade. From 1930 to 1941, at least some part of the country was afflicted; drought conditions peaked in severity in 1930, 1934, 1936, 1939, and 1940.

During 1953 and 1954, drought affected 51 percent of the country. Typically, however, droughts tend to be regional. The drought of the 1950s may have been the worst to strike the American Southwest in seven hundred

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[1] Richard R. Heim, Jr., "About That Drought," *Weatherwise* 41, no. 5 (October 1988): 266.

[2] M. A. Beran and J. A. Rodier, *Hydrological Aspects of Drought* (Paris, France: UNESCO and The World Meteorological Organization, 1985), 124.

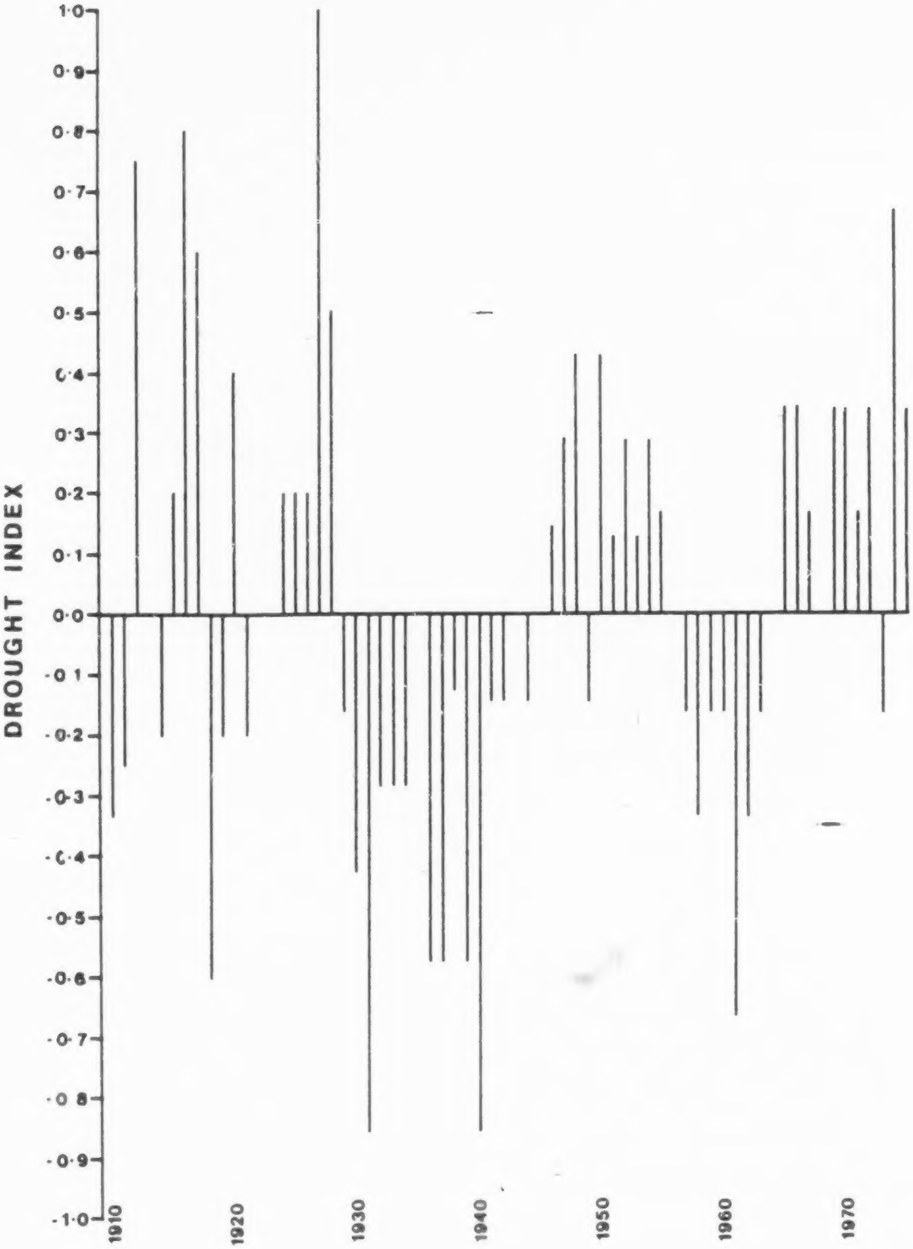

Fig. 5-1. Drought index for the northern prairie states and adjacent parts of Canada based on the proportion of studied rivers experiencing conditions drier or wetter than the 5-year return period level, as depicted in M. A. Beran and J. A. Rodier, *Hydrological Aspects of Drought* (Paris, France: UNESCO and The World Meteorological Organization, 1985), 124.

years.[3] Northwest Texas, for example, experienced drought conditions from mid-1952 to early 1957.[4] Severe localized droughts also struck the Southwest and southern Great Plains in 1971, 1972, and 1974; the Far West and northern Plains and northern Great Lakes regions in 1976 and 1977; and scattered parts of the country in 1980 and 1981. Indeed, the 1988 drought continued the dry spell that the Southeast had experienced since 1984 and that the West had experienced since 1987.

Progress of the Drought[5]

In retrospect, the 1988 drought can be traced to 1987 for parts of the country. The West, northern Rockies, northern Plains, and southern Appalachians experienced unusually dry conditions during the winter months when winter temperatures averaged up to 4° F above normal in Montana and North Dakota, and precipitation in parts of Montana and the northern Great Basin was less than half of normal. Parts of California, Arizona, and northern New York and New England had winter temperatures approximately 2° F above normal.

Spring 1988 brought above-average temperatures to most of the northern tier; it was the warmest spring on record in some locations. In northeastern Montana and North Dakota, for example, temperatures were as much as 6° F above normal, and in Minnesota, temperatures were more than 8° F above normal.

The spring also brought below-average rainfall to much of the country. Rainfall in Minnesota, Montana, and North Dakota totaled less than 0.5 inch. The central United States--centered around the Mississippi River and its tributaries--received less than 75 percent of normal spring rainfall. By late spring Old Man River was at its lowest recorded level. Large parts of

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[3] Patrick Hughes, "The Worst Droughts of the 20th Century," *Weatherwise* 41 no. 5 (October 1988): 268.

[4] Heim, "About That Drought," 270.

[5] This discussion is based on Doug LeComte, "A Sun-Baked Summer in the U.S.," and A. James Wagner, "Persistent Circulation Patterns," *Weatherwise* 42, no. 1 (February 1989): 13-16 and 18-21, respectively.

Iowa, Tennessee, and northeast Texas had less than half their normal rainall. For many cities in the central United States, May 1988 was the driest on record. The dryness led to severe dust storms in Minnesota and North and South Dakota, causing crop damage and hazardous road conditions.

During the summer months, most of the country experienced above-average temperatures. Parts of Wyoming, Montana, and North Dakota had temperatures of 6° F above normal. The Rocky Mountain states and western north-central states endured their third-hottest summer since 1931. The eastern north-central states had their hottest summer since 1931. June was the hottest month recorded in the northern Plains in thirty-eight years, while August brought record and near-record high temperatures to the Midwest, Northeast, and most of the Atlantic seaboard. Oddly, Southwestern Texas was the only region of the country that enjoyed a relatively cool summer, with temperatures averaging as much as 2° F below normal.

More than one-third of the country experienced severe drought conditions in June. Summer rainfall was below normal across a huge area stretching from the northern Plateau to the northern half of the Mississippi Valley, to parts of the Great Lakes states, and to the Ohio and Tennessee valleys. The cumulative rainfall deficit reached its most critical point in early July. The drought conditions indicated by the Palmer long-term drought severity index peaked in mid-July when severe or extreme drought gripped 45 percent of the country. Later that month, rain arriving from the Gulf of Mexico brought temporary relief to the Ohio Valley, although dry weather continued in the northern Plains and upper Mississippi Valley. Drought severity maps based on Palmer index values across the nation are published biweekly in the U.S. Department of Agriculture's *Weekly Weather and Crop Bulletin*. Figures 5-2 and 5-3 allow a comparison of drought conditions for 1987 and 1988 from that source.[6]

In August, heavy rainfall fell on parts of the northern Mississippi Valley and Great Lakes states; too late, however, to save major portions of

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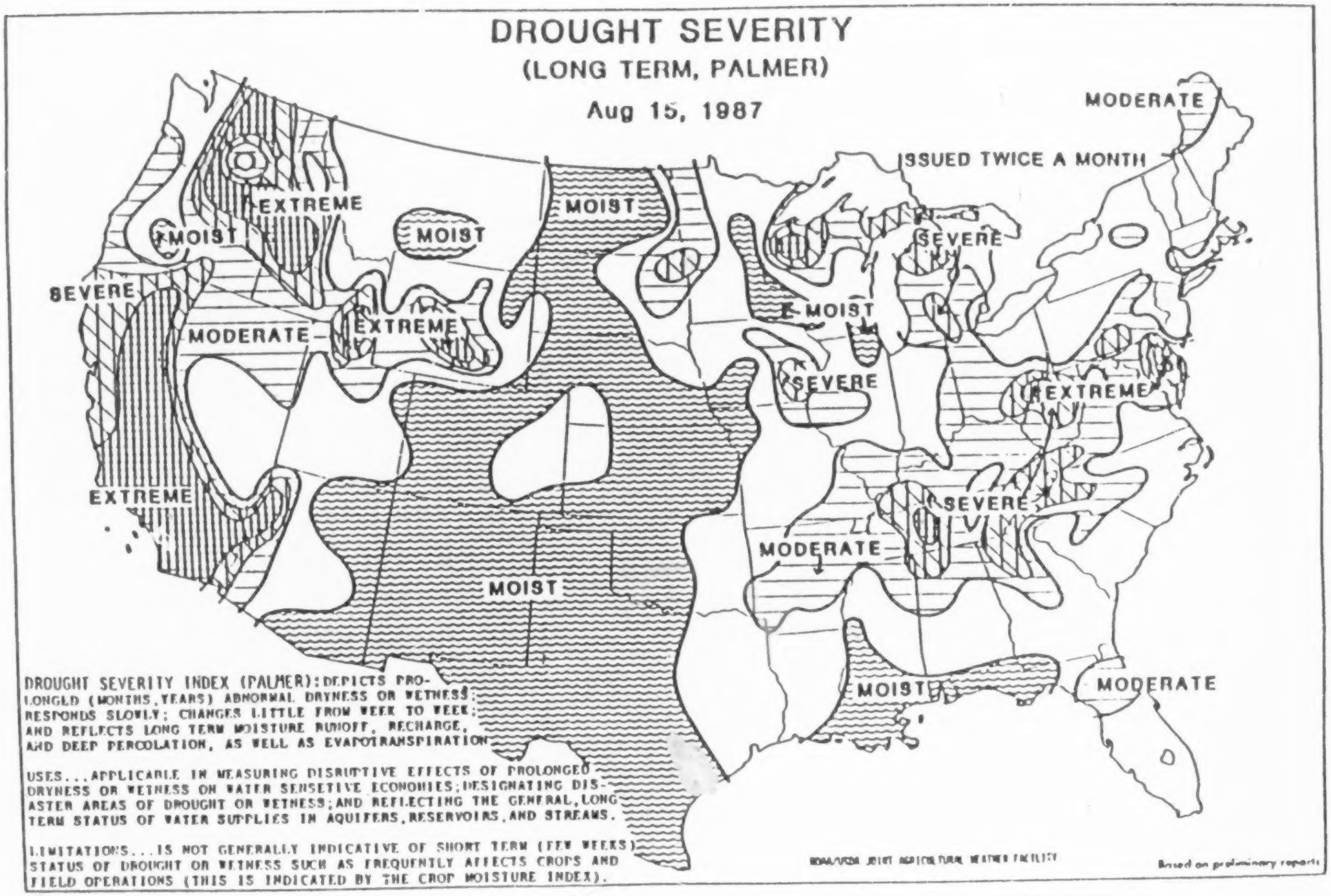
[6] The long-term drought severity maps based on the Palmer index illustrated the lingering effects of drought well into the summer of 1989.


DROUGHT SEVERITY
(LONG TERM, PALMER)
Aug 15, 1987
ISSUED TWICE A MONTH
MODERATE
SEVERE
EXTREME
MOIST
MOIST
EXTREME
MODERATE
EXTREME
MOIST
MOIST
SEVERE
MOIST
SEVERE
EXTREME
SEVERE
MODERATE
MOIST
MOIST
MODERATE

DROUGHT SEVERITY INDEX (PALMER): DEPICTS PROLONGED (MONTHS, YEARS) ABNORMAL DRYNESS OR WETNESS; RESPONDS SLOWLY; CHANGES LITTLE FROM WEEK TO WEEK; AND REFLECTS LONG TERM MOISTURE RUNOFF, RECHARGE, AND DEEP PERCOLATION, AS WELL AS EVAPOTRANSPIRATION

USES... APPLICABLE IN MEASURING DISRUPTIVE EFFECTS OF PROLONGED DRYNESS OR WETNESS ON WATER SENSETIVE ECONOMIES; DESIGNATING DISASTER AREAS OF DROUGHT OR WETNESS; AND REFLECTING THE GENERAL, LONG TERM STATUS OF WATER SUPPLIES IN AQUIFERS, RESERVOIRS, AND STREAMS.

LIMITATIONS... IS NOT GENERALLY INDICATIVE OF SHORT TERM (FEW WEEKS) STATUS OF DROUGHT OR WETNESS SUCH AS FREQUENTLY AFFECTS CROPS AND FIELD OPERATIONS (THIS IS INDICATED BY THE CROP MOISTURE INDEX).

NOAA/USDA JOINT AGRICULTURAL WEATHER FACILITY

Based on preliminary reports

Fig. 5-2. Drought severity, 1987 as depicted in *Weekly Weather and Crop Bulletin* 74, no. 33 (August 18, 1987): 4.

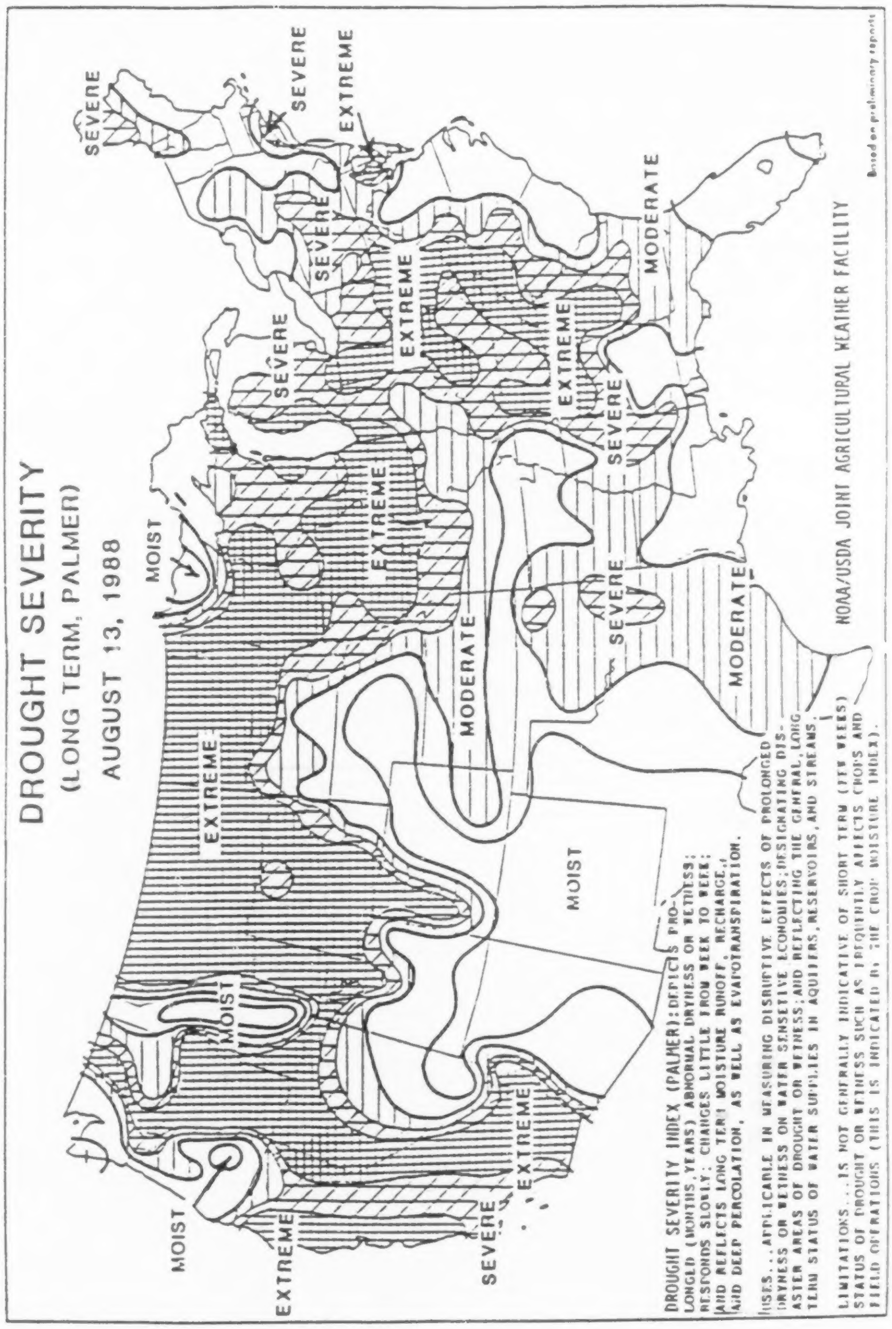

DROUGHT SEVERITY
(LONG TERM, PALMER)
AUGUST 13, 1988
MOIST
EXTREME
SEVERE
EXTREME
MOIST
EXTREME
EXTREME
MOIST
MOIST
EXTREME
MODERATE
MODERATE
SEVERE
MODERATE
EXTREME
SEVERE
EXTREME
SEVERE
SEVERE
EXTREME
SEVERE
SEVERE
SEVERE
EXTREME
MODERATE
DROUGHT SEVERITY INDEX (PALMER): DEPICTS PROLONGED (MONTHS, YEARS) ABNORMAL DRYNESS OR WETNESS; RESPONDS SLOWLY; CHANGES LITTLE FROM WEEK TO WEEK; AND REFLECTS LONG TERM MOISTURE RUNOFF, RECHARGE, AND DEEP PERCOLATION, AS WELL AS EVAPOTRANSPIRATION.
USES... APPLICABLE IN MEASURING DISRUPTIVE EFFECTS OF PROLONGED DRYNESS OR WETNESS ON WATER SENSITIVE ECONOMIES; DESIGNATING DISASTER AREAS OF DROUGHT OR WETNESS; AND REFLECTING THE GENERAL, LONG TERM STATUS OF WATER SUPPLIES IN AQUIFERS, RESERVOIRS, AND STREAMS.
LIMITATIONS... IS NOT GENERALLY INDICATIVE OF SHORT TERM (FEW WEEKS) STATUS OF DROUGHT OR WETNESS SUCH AS FREQUENTLY AFFECTS CROPS AND FIELD OPERATIONS (THIS IS INDICATED BY THE CROP MOISTURE INDEX).
NOAA/USDA JOINT AGRICULTURAL WEATHER FACILITY
Based on preliminary reports

Fig. 5-3. Drought severity, 1988 as depicted in *Weekly Weather and Crop Bulletin* 75, no. 33 (August 16, 1988): 4.

corn and hay crops. Mid-August brought moisture and cooler temperatures to the Midwest and Northeast; even in these areas, however, the drought was not over, since a critical long-term soil-moisture deficit persisted.

During autumn 1988, above-average temperatures lingered from the Rocky Mountains to the West Coast; seasonal mean temperatures averaged 2° to 4° F above normal. Gulf Coast states and southern Florida also experienced slightly above-average temperatures. In the Midwest and north- and middle-Atlantic states, however, temperatures were about 1.5° to 2.5° F degrees below normal. Relatively heavy rains fell over the Great Lakes, parts of the Ohio, Mississippi and Tennessee valleys, and most of the Southeast, helping to lessen much of the soil-moisture deficit from the summer. However, severe drought still gripped large areas of the northern Plains and northern Rockies.

Annual accumulated precipitation at year's end showed that most of the country had below-normal rainfall during 1988, and that portions of the northern and central Plains received less than 60 percent of normal precipitation.

Causes of the 1988 Drought

Meteorologists continue to look for reliable explanations of the continent's weather patterns. The 1988 drought is widely believed to have been caused by unusual Pacific Ocean temperatures. The first two theories summarized below are based on this belief. The third theory, that the 1988 drought might have been due to global warming (or the "greenhouse effect"), is not widely accepted by the scientific community.

El Niño

The drought that affected the United States in 1988 was associated with anomalies in the atmospheric circulation of the Northern Hemisphere that may have been caused by unusual changes in tropical sea surface temperatures, according to meteorologists Kevin E. Trenberth, Grant W. Branstator, and Phillip A. Arkin.[7]

Based on their research of historic ocean temperatures and atmospheric circulation patterns, and on the results of atmospheric modeling, these scientists suggest that the principal cause of the 1988 drought was unusual sea surface temperatures in the tropical Pacific Ocean in late 1987 and early 1988. El Niño, the name given to unusually warm tropical Pacific Ocean water that sometimes appears in late December along the equator from South America to the central Pacific, was in a different pattern than normal during these months. In 1988, as typically expected, El Niño spawned a strong high pressure ridge near the western coast of the United States, splitting the jet stream. The southern branch of the jet stream was less active than normal, however, and did not bring wet weather to southern California as it usually does. The jet stream's northern branch, moreover, was much farther north than normal, causing displacement of the storms that usually follow the jet stream; these storms moved northward to the Gulf of Alaska rather than bringing rain to the West and northern Plains states.

Pacific Ocean Temperatures

A slightly different theory about the cause of the 1988 and other droughts in the farm belt region has been put forward by atmospheric scientist Ernest Kung.[8] Based on his analysis of ocean and surface temperature records from 1964 to 1980, Kung believes that an inverse relationship exists between the water surface temperatures in the north-central Pacific Ocean and the land surface temperatures of the central United States about three months later. Kung contends that when ocean temperatures drop more than 1.5° C below average in early spring, a hot dry summer can be expected in the farm belt.

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[7] Kevin E. Trenberth, Grant W. Branstator, and Phillip A. Arkin, "Origins of the 1988 North American Drought," *Science* 242 (December 1988): 1640-5.

[8] Ernest Kung, "Pacific Temperatures Help Predict Weather," *Oceans* 21, no. 5 (September-October 1988): 6.

Global Warming

Scientists generally do not support the notion that the 1988 drought was caused by global warming or the "greenhouse effect," the theory that the world's atmospheric temperatures are warming due to increases in carbon dioxide, methane, chlorofluorocarbons, and other gaseous emissions into the air. As Stephen H. Schneider of the National Center for Atmospheric Research recently stated in testimony before the U.S. House of Representatives, the greenhouse effect may increase the likelihood of future drought conditions, but cannot be blamed for a specific drought occurrence:

> The strongest statement one could make responsibly, given the uncertainties, is that increasing the global average temperature could increase evaporation stress, thereby slightly altering the odds toward increased drought. However, as is well known by all atmospheric scientists, droughts are generally a result of unusual patterns of atmospheric circulation, whose causes are not clear cut and most often are ascribed to unusual temperature patterns in the oceans.[9]

Effects of the Drought[10]

Along with searching for the causes of drought, there is also a great deal of interest in investigating its consequences. Effects of the 1988 drought can be broadly classified in terms of aggregate economic activity, and effects on power generation, agriculture and livestock, forestry, transportation, and wildlife.

Aggregate Economic Activity

Although the 1988 drought severely affected some sectors of the United States economy, the President's Interagency Drought Policy Committee concluded that its ill effects on the country as a whole were relatively small. The loss of farm sector productivity, for example, reduced the Gross National Product only 0.7 percent. The Committee did not quantify the loss of production in sectors other than the farm sector. The Committee projected that the drought-induced increase in the retail price of agricultural products would raise the 1988 Consumer Price Index by no more than 0.2 percent, and would be unlikely to affect consumer prices in 1989.

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[9] Steven H. Schneider, "Global Warming: Scientific Reality or Political Hype?" testimony before the Subcommittee on Energy and Power of the House Committee on Energy and Commerce (February 21, 1989), 2.

[10] This discussion is based on *The Drought of 1988: Final Report of the President's Interagency Drought Policy Committee* (Washington, DC: U.S. Government Printing Office, 1988).

Power Generation

The Committee gave several examples of production capacity reductions made due to inadequate water supplies during the summer of 1988. Several steam power plants, including the Mid-Continent Area Power Pool (MAPP), Tennessee Valley Authority (TVA), and Southwest Power Pool (SPP), did not have enough cooling water available for full operation; hydroelectric capacity for the MAPP area, for example, was reduced by about 13 percent.

In addition, the Committee reported that eleven power plants operated by the U.S. Army Corps of Engineers in Alabama, Georgia, and South Carolina, as well the Corps' Missouri River Main Stem projects, had substantial reductions in power production. The U.S. Department of Energy consequently had to purchase millions of dollars worth of replacement energy to meet its contractual commitments. In total, the Corps' annual power generation was down by about 23 percent.

Nuclear power production was also affected by the drought in some areas. The Committee stated that special reservoir operations were necessary at the Sequoyah Nuclear Plant to provide cold water from upstream reservoirs to meet emergency raw-cooling-water temperature limits.

Agriculture and Livestock

The Drought Policy Committee called the 1988 drought "the most pervasive early season drought ever to hit the heart of the Farm Belt during the critical growing months."[11] The Committee reported that the drought resulted in:

- $13 billion in lost farm production.
- A reduction in crop production (by comparison to 1987) of 34 percent for corn and feed grains, 21 percent for soybeans, 54 percent for spring wheat, 10 percent for sugar beets, 24 percent for dry edible beans, 9 percent for potatoes, and 42 percent for tart cherries.
- The smallest harvested crop acreage ever seen this century--284 million acres.
- A reduction in the country's soybean stock to less than one month's supply and a reduction in wheat, corn, barley, and grain sorghum carry-out stocks.
- An increase in cash crop receipts of 11 percent and in livestock cash receipts of 5 percent (as compared to 1987).
- A change in income distribution, as farmers outside drought areas increased their incomes, while farmers within drought areas lost income.
- A direct income loss of 1 percent to 18 percent and a decrease in total business activity of 1 percent to 22 percent in some communities.
- Above-average price increases for fruits, vegetables, and cereal and bakery products. The drought increased 1988 food prices by 0.5 percent.
- Range forage production of only 50 percent to 80 percent of normal in severely affected drought areas.
- Higher feed prices for livestock, dairy, and poultry farmers.
- A slowing of the expansion of American cattle herds and an approximate 1 percent increase in cattle and hog slaughter.

The Drought Policy Committee also expected that some effects of the drought would be felt during the 1989 food production year. For example, drought-stressed plants in severely affected range forage areas--Montana, Wyoming, North and South Dakota, northern Utah, southern Idaho, and Nevada--were not expected to recover to their full vigor for the 1989 season; the federal government, therefore, planned to reduce the number of livestock allowed to graze on federal lands. The committee believed, moreover, that the amount of wheat and feed grain cropland set aside under federal acreage reduction programs probably would be cut back sharply for the 1989 growing season.

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[11] Ibid., 58.

The Drought Policy Committee found, however, that the agricultural impacts of the drought were mitigated by a number of factors. First, shortages of grain, soybeans, and corn were moderated because stored food supplies were used. Second, the federal government allowed haying on acreage that previously had been removed from production under acreage reduction and conservation reserve programs. This increased the available haying acreage by 10 percent. Third, higher crop and livestock prices helped to offset reduced crop production and also helped to reduce the federal government's price support payments. As a result, 1988 net cash income was estimated to be similar to that of 1987, which was a record $57.1 billion. Finally, the Committee reported that the federal government would make drought relief payments of $6 to $8 billion for crop losses, feed assistance, and federal crop insurance in 1988 and 1989.

The Committee apparently did not believe that the long-term agricultural effects of the 1988 drought would be severe. The report stated:

> [H]istorical data suggest that crop production will rebound and stocks will start to reaccumulate. Moreover, there is no evidence that the drought has changed the long-term tendency for agricultural productivity to outpace the growth in demand for farm products.[12]

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[12] Ibid., xiii.

Forestry

The hot, parched summer of 1988 led to a series of forest fires in western states, particularly in Wyoming, Montana, Oregon, California, Washington, and Idaho. According to the Drought Policy Committee, more than 72,750 fires nationwide burned over five million acres, including national forest lands worth more than $70 million. Fire-fighting efforts cost in excess of $600 million and required 41,000 fire fighters including National Guard, Army, and Marine battalions mobilized to reinforce civilian crews. The fires destroyed 357 homes and killed nine people.

The drought also caused a high mortality rate among tree seedlings planted in 1988, while in some areas saplings up to ten years old died. Excluding orchards and Christmas tree plantations, about 250 million tree seedlings and 350,000 acres of young forest plantations were lost. In addition, the Committee estimated that up to 4.7 billion board feet of wood, much of it on federal lands, might be lost due to insect infestation of trees weakened by the drought.

Damage to the nation's forest reserves may result in a reduction in the timber harvested from public lands during the next ten to twenty years. Moreover, major salvage efforts for burned and insect-infested trees may be necessary in some areas.

Transportation

Many of the nation's primary shipping waterways were affected by the 1988 drought. The Apalachicola, Chattahoochee, and Flint river systems were closed for most of the summer due to low water levels. The middle and lower Mississippi and lower Ohio rivers were at record low water levels. The Mississippi, Ohio, Alabama, Missouri, and White Rivers required dredging because of the drought. Restrictions placed by the Coast Guard on shippers on the lower Ohio and lower Mississippi rivers reduced the volume of loads moved by towboat as much as 50 percent, which reduced the amount of grain and coal transported by barge. Barge industry losses were estimated at $60 million to $65 million.

The drought increased traffic on the lower Tennessee River and Tennessee-Tombigbee Waterway, however, as well as on the Great Lakes and the

St. Lawrence Seaway. In addition, railroads and trucks transported some of the shipments normally moved by barge. The pressures on the nation's transportation systems were eased, moreover, by decreased agricultural production. By the end of September, barge traffic had resumed normal or near-normal levels (compared to 1987) and the Drought Policy Committee projected that the nation's inland barge industry would not suffer any severe long-term effects. However, accelerated freezing in the northern parts of the waterways during the winter of 1988-1989 was feared because of the lower water levels.

Wildlife

The Drought Policy Committee emphasized the significant impact the 1988 drought had on ducks. Duck breeding populations were most severely affected in the northern prairies, where the loss of marshlands due to the drought caused a 53 percent reduction in breeding pairs and a 75 percent reduction in the number of ducklings. In addition, duck breeding habitat was lost because of the emergency haying permitted on thousands of acres of upland cover, including waterfowl protection areas, wildlife management areas, highway rights-of-way, and conservation reserve program lands. Available food supplies for waterfowl was limited because of reduced crop production.

The loss of habitat and food supplies and the consequent reduction in duck population is likely to have a great affect on future duck populations, the Committee stated:

> The prognosis for next year's duck breeding season is bleak because a reduced number of breeders are expected to return to the northern prairies and, without far-above-normal fall and winter precipitation, pond conditions will be worse at the beginning of 1989 than in 1988.[13]

The full impact of the drought on the nation's fish population will not be known until the 1988 hatchlings mature. It appears, however, that the hardest hit will be those fish that spawn in the spring in intermittent streams, small streams, the headwaters of larger stream systems, and small ponds. In addition, water quality levels were generally poorer because less water was available to dilute water pollutants and because of increased vegetative growth.

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[13] Ibid., xiv.

Wildlife habitat for many other species, including threatened or endangered species, was also hurt by the drought. The riparian nesting habitats of many birds, such as least terns and piping plovers, were drastically reduced. Overgrazing of drought-stressed grasses reduced the range available to Attwater's prairie chicken and other grassland animals. Emergency haycutting on acreage-reduction areas destroyed many animal nesting areas.

Government Responses to the Drought

It would be impossible at this time to provide a comprehensive account of government responses to the 1988 drought, since some of these responses are ongoing or still being initiated. The following discussion, however, provides examples of some of the measures taken to mitigate the impact of the drought.

The crisis atmosphere created by the 1988 drought led to passage of two federal statutes. The Disaster Assistance Act of 1988 authorized spending approximately $3.9 million for drought assistance. This augmented the almost $3 million in drought assistance funding already authorized under existing emergency feed assistance and federal crop insurance programs.[14] The Reclamation States Drought Assistance Act of 1988 authorized spending $25 million to fund new drought-mitigation activities that the Secretary of the Interior may undertake, including the completion of water conservation studies for federal reclamation and American Indian water projects, assisting buyers and sellers in water marketing, and making emergency water management and conservation loans.[15]

In the wake of the 1988 drought, some states took more proactive planning and response roles in the areas of water supply.[16] The twelve midwestern states responded to the 1988 drought in a variety of ways.[17] As reflected in table 5-1, all twelve established drought telephone hot-lines to provide information on hay location, weather, or water levels. By late July, all or parts of Indiana, Missouri, Ohio, and Wisconsin had been designated federal disaster areas, with other areas pending designation. The midwestern states also pressed insurance companies to meet their obligations under drought insurance policies sold to consumers in those states.

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[14] Ibid., 49.

[15] Ibid., 52.

[16] American Water Works Association, "Drought Triggers Restrictions, Conservation Measures," *Mainstream* 32, no. 9 (September 1988): 8-9.

The California State Legislature acted to improve drought mitigation measures. The state had suffered drought conditions since 1987 and faced the possibility of a continued drought in 1989.[18] Senate Bill 32, signed into law in September 1988, directed the Department of Water Resources to develop guidelines to identify areas in California that could be severely affected by continued drought, and to develop guidelines to coordinate the drought responses of California's water agencies.

In these guidelines, published by the Department of Water Resources in January 1989, several drought management options are identified, including water rationing and conservation, increased use of groundwater, water transfers, and the development of temporary facilities that will help save water and improve water quality and water circulation. The manual is one of the most comprehensive available in both assessing water supply conditions and preparing for the possibility of drought conditions. It provides general options for responding to a dry 1989 and also spells out contingency plans for five major urban water suppliers.

In addition to these actions, several state public utility commissions have adopted drought policies that affect regulated water utilities. These include orders from the California, Ohio, and West Virginia commissions as well as the Texas Water Commission's tariff specifications pertaining to its Emergency Water Rationing Program, described briefly below:

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[17] Information on the midwestern states' reactions to the drought is from David E. Ensign, *Update: Midwestern States' Response to the Drought* (Lombard, IL: Midwestern Legislative Conference of the Council of State Governments, August 1988.)

[18] Information on California's drought mitigation measures is based on two reports by the California Department of Water Resources (Sacramento, CA): *Drought: Contingency Planning Guidelines for 1989* (January 1989) and *Drought Assistance* (January 1989).

- A March 1989 order by the Public Utilities Commission of California required the staff to investigate measures to mitigate the effects of drought on regulated water utilities, their customers, and the public. All Class A, B, and C water utilities were required to submit information to the commission, which was used in two reports issued in the spring of 1989.
- An April 1989 order by the Public Utilities Commission of Ohio reiterated a policy adopted in 1988 that authorized all water utilities experiencing emergency water shortages to restrict water consumption as necessary to provide adequate water supplies for public fire protection and basic human needs. The order also set standards for enforcing user restrictions imposed by water utilities.
- A rule adopted in April 1989 by the West Virginia Public Service Commission established requirements for water use during periods of inadequate water supply, including the provision that all water purveyors must develop and enforce a local water rationing plan. The rule also defined nonessential water uses and prohibited these uses within any water emergency area.
- The Texas Water Commission's Emergency Water Rationing Program is part of the water utility tariff required for all water utilities in Texas. The rationing program sets out the circumstances under which a water utility may declare an emergency and specifies how emergency water rationing must be carried out and enforced.

Government coordination and cooperation is obviously important to an effective drought response. In many instances, however, drought and methods of drought mitigation also tend to increase the potential for *conflict* among government entities at the local, state, national, and even international levels. The 1988 drought, for example, stepped up the debate over possible diversions of water from Canada to the United States.[19] Droughts can thus embroil governments in the ever intensifying competition for water.

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[19] John Daly, "The Real Value of a Treasure," *Macleans* 101 (June 27, 1988): 40.

TABLE 5-1

RESPONSE OF MIDWESTERN STATES TO THE 1988 DROUGHT

State	"800" Hot Line	Burning Restrictions	Federal Disaster Request	Special Legis-lative Session	Number of Counties Allowing Haying on Set-aside Acreage	Drought Task Force	Drought Fund	Programs for Migrants
Illinois	Hay	No	Pending	No	102/102 counties	Standing body	No	- - -
Indiana	Water; Hay	Statewide July 1-26	Designated July 19	No	92/92	Standing body	Pending	A task force was considering this
Iowa	Info; Hay	No	Pending	No	99/99	Standing body	No	No
Kansas	Info; Hay	By county	No request	No	63/105	Appointed in May	No	No
Michigan	Info	Statewide; lifted July 28	Pending	No	83/83	No	Econ. Dev. Fund may be released	Augmenting existing programs
Minnesota	Hay	Approx. 20 counties	Pending	No	87/87	Standing body	Yes	Money for housing
Missouri	Hay	North of Missouri R.	Designated July 13	Yes	114/114	Appointed in the spring	Yes	No
Nebraska	Info	No	No request*	No	68/92**	Standing body	No	No
North Dakota	Info	Statewide since April	Pending	No	53/53	Contingency plan triggered in May	No	No
Ohio	Hay	Statewide	Designated July 4	Being considered	88/88	Formed in mid-June	Yes	No
South Dakota	Hay	Federal land, state forests, and recreation areas	Pending	No	55/66**	Standing body	No	No
Wisconsin	Hay; Info	Statewide; lifted late July	Designated July 22	Yes	72/72	Appointed in the spring	No	No

Source: David E. Ensign, Update: Midwestern States' Response to the Drought (Lombard, IL: Midwestern Legislative Conference of the Council of State Governments, August 1988).

* Two counties bordering Missouri qualify.

** All counties in Nebraska and South Dakota are open for hay donation under an Agricultural Stabilization and Conservation Service program.

One manifestation of this competition is the apparent conflict between urban and rural communities in the West. The suburb of Thornton, Colorado, for example, recently purchased 21,000 acres of farmland in outlying communities in order to gain control of the irrigation allotments for that land. Rural residents, fearing a raid on their water supply by neighboring urbanites, challenged the land sale in court. Water diversions from rural areas to urban areas also are being attempted--and fought--from Washoe County, Nevada to Reno; from the Hudson River Valley to New York City; and from the Virginia-North Carolina border to Virginia Beach.[20]

It is, therefore, not a foregone conclusion that the 1988 drought or future drought conditions will result in improved water planning or new government cooperation. It is clear, however, that as drought conditions recur, there is a greater likelihood that state commissions and other government authorities will be called upon to adopt policies affecting jurisdictional water utilities, particularly during periods of shortage.

Some Lessons from the 1988 Drought

The President's Drought Policy Committee found that the drought exposed weaknesses in the government's ability to respond to extreme drought conditions. Many of these weaknesses related to a lack of adequate drought contingency plans and to increased competition for limited water resources. The Committee believed that improvements in drought response capabilities should include the following:[21]

- Preparation of drought contingency plans and low-flow operating guidelines for reservoirs and the inland waterways system with periodic review and update of these plans and guidelines.
- Development of water conservation and improved water use efficiency plans.[22]

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[20] Joseph P. Shapiro, et al., "First Volleys of New Water Wars," *U.S. News and World Report*, May 30, 1988, 20-22.

[21] *The Drought of 1988: Final Report of the President's Interagency Drought Policy Committee*, 58-63.

[22] The Committee stated that this was a responsibility of state governments, with the assistance of the U.S. Departments of Agriculture and the Interior.

- Better management and control of groundwater resources to assure their efficient use and maintenance of aquifers.

- Use of contingency plans that balance the need for wildlife habitat with the need for increased dredging, emergency water withdrawals, and groundwater use during droughts.

- Analysis of the constraints and inefficiencies that exist in the nation's inland waterways transportation system.

- Improvement in the ability to forecast water flow levels for navigation.

- Maintenance of wildlife habitat through the Conservation Reserve Program and other acreage set-aside programs.

While the Drought Policy Committee did not call for any changes in agricultural policy in response to the drought, others believe that the drought demonstrated the need for dramatic changes in food production. The *New Republic* was critical of American farm support programs, which buy up overly abundant crops at artificially high prices one year and provide drought assistance to farmers who suffer from lower production levels the next.[23] Lester Brown, president of Worldwatch Institute, expressed concern that United States farm policies and economic pressures encourage farmers to cultivate highly erodible acreage, resulting in the loss of "billions of tons" of topsoil every year, and to pump groundwater from aquifers in excess of the normal rate of recharge.[24] An article in *Field and Stream* magazine proposed several changes needed to protect the nation's natural resources and its wildlife habitat through changes in the Conservation Reserve Program (CRP) that would:[25]

- Provide additional cost-sharing funds to landowners who improve their land-use practices on existing CRP acreage.

- Give financial incentives to farmers to restore wetlands instead of simply planting grasses and legumes.

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[23] "They Asked For It," *The New Republic*, July 18-25, 1988, 4-5.
[24] "Drought for Thought," *Science News* 134 (September 24, 1988): 204.
[25] Maggie Nichols, "Drought '88," *Field and Stream*, December 1988, 54 and 95-97.

- Allow all restorable wetlands to be included in the CRP, not only those that are on highly erodible land.
- Restrict future emergency haying under the CRP, if it is allowed, to seasons other than the peak nesting season.

In addition, this assessment called for modification of the provision frequently included in crop insurance policies that requires fields to be plowed under in order for farmers to collect insurance.

The 1988 drought has provided governments and water suppliers with an opportunity to take action to improve their emergency response capabilities. Although extreme drought conditions did not persist in 1989 for most parts of the country (with southern Iowa being a notable exception), they will eventually return. Whether lessens are learned from the 1988 drought will only be known with the next drought.

CHAPTER 6

DROUGHT PLANNING AND MANAGEMENT

Droughts come and go. One of the chief reasons for inadequate drought planning is the fact that concern about drought is inversely related to precipitation. When the rains come, interest by the public, by the media, by government, by water suppliers, and even by the scientific community tends to wane. The sense of worry is replaced by a sense of apathy, as depicted in figure 6-1. Kenneth Frederick explains this phenomenon with respect to droughts in the early 1980s:

> In 1980 and 1981, when large areas of the United States were parched by drought, alarmist reports on the state of the nation's water supplies received wide coverage. . . . Then, as more normal patterns of precipitation returned, the crisis atmosphere receded and the urgency for action waned. Little, if anything, has been done to enable most regions to prevent or cope more effectively with future shortages of water. Although no one knows for certain when the next drought will develop, we do know that it will come.[1]

As discussed in chapter 5, drought conditions returned to the continental United States only a few years later. The key to drought management and mitigation is to overcome the tendency toward apathy during wet years and prepare for the inevitable dry years. As Frederick suggests, future drought is a certainty. Adequate planning for drought is far less certain. This chapter addresses ways to plan for and manage the effects of inevitable droughts.

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[1] Kenneth D. Frederick, "Overview," in Kenneth D. Frederick, ed., *Scarce Water and Institutional Change* (Washington, DC: Resources for the Future, 1986), 1.

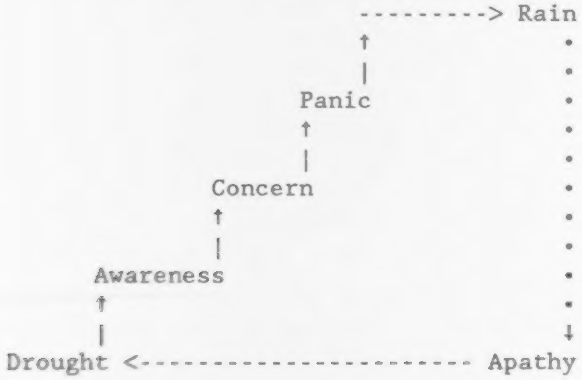

Fig 6-1. The human response to drought as adapted from Howard F. Matthai, "Drought Impacts on People," in David H. Speidel, et al., eds., *Perspectives on Water: Uses and Abuses* (New York: Oxford University Press, 1988), 190.

Crisis Management v. Risk Management

Societies use a variety of techniques to adjust to nature including engineering mechanisms (technological solutions), symbolic mechanisms (sociocultural solutions), regulatory mechanisms (policy solutions), and distributional mechanisms (resource management solutions).[2] Societal responses to virtually any disaster, including drought, generally fall within one of these categories. When disasters strike, societies may choose from among a number of policies. According to one study, there are four general types of policy responses to disasters: disaster relief, control of natural events, comprehensive reduction of damage potential, and combined multihazard management.[3]

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[2] Adapted from Vujica Yevjevich and Evan Vlachos, "Strategies and Measures for Coping with Droughts," in Vujica Yevjevich, Luis da Cunha, and Evan Vlachos, eds., *Coping with Droughts* (Littleton, CO: Water Resources Publications, 1983), 78.

[3] Ibid.

The choice of drought-coping strategies may depend on the philosophical disposition of those making the choice. Donald A. Wilhite and William E. Easterling concluded that prevailing drought policy reflects a philosophy of crisis management rather than risk management, not just in the United States but around the globe:

> Whether referring to the well-documented recent tragedies of Ethiopia or the economic impacts of the 1986 drought in the southeastern United States, the message seems clear--society has typically chosen to react (i.e., employ crisis management) to drought rather than prepare (i.e., employ risk management) for it. With few exceptions this approach has been, at best, ineffective.[4]

Put another way, strategies for coping with drought can be either reactive or anticipatory.[5] Anticipatory strategies involve planning for drought while reactive strategies occur when drought conditions actually materialize. A series of disastrous events may cause a shift of resources in the direction of more anticipatory strategies to prepare for future disasters.

For man-made disasters, anticipatory strategies may include preventive measures such as policies geared toward pollution prevention. Natural disasters, of course, cannot be prevented. Resources may, however, be devoted to predicting their occurrence, spreading risks, and mitigating their effects. Over time, societies also adapt to the environment, mitigating nature's adversities.

Examples of anticipatory or risk management strategies for minimizing the effects of drought are most readily available in the agricultural sector.[6] Anticipation involves the use of forecasting and warning mechanisms as well as follow-up procedures for these mechanisms. Spreading the risk of loss can be accomplished through drought insurance, individual protection (storage and savings), disaster aid, the use of hardy plant species, and adjustments in agricultural practices.[7] Of course, some of these measures also may be applied in the area of nonagricultural vegetation.

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[4] Donald A. Wilhite and William E. Easterling, eds., *Planning for Drought: Toward a Reduction of Societal Vulnerability* (Boulder, CO: Westview Press, 1987), preface.

[5] L. Douglas James, Evan Vlachos, and Lucien Duckstein, "Institutional Adjustments and Modifications," in Yevjevich, da Cunha, and Vlachos, eds., *Coping with Droughts*.

[6] Yevjevich and Vlachos, "Strategies and Measures for Coping with Droughts," in Yevjevich, da Cunha, and Vlachos, eds., *Coping with Droughts*, 86.

In general, anticipatory planning for drought and other disasters may include a variety of activities by water suppliers and government agencies. According to the U.S. Army Corps of Engineers, adequate drought planning includes the development of:[8]

- Procedures for alerting the public to a drought.
- Methods for assessing the magnitude of the expected drought-induced water supply deficit (short-run streamflow prediction).
- Models for forecasting the increased water consumption related to drought conditions.
- Methods for estimating the potential demand reduction and supply conservation measures and the evaluation of their applicability, technical feasibility, social acceptability, implementation conditions, and cost-effectiveness.
- Methods for determining monetary losses associated with various cutbacks in water delivery to various user categories and to the water utility itself.
- Mathematical optimization procedures including sensitivity analysis.

Anticipatory planning essentially entails the development of reliable information resources and decision tools in advance of a crisis situation. In any water shortage situation managers face choices--sometimes tough choices--made more difficult without planning. The planning period before the crisis can be used to develop a variety of management strategies designed to mitigate the effects of drought.

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[7] On agricultural adjustments, see Richard A. Warrick, *Drought Hazard in the United States: A Research Assessment* (Boulder, CO: Natural Hazards Research and Applications Information Center, University of Colorado, 1975).

[8] Benedykt Dziegielewski, Duane D. Baumann, and John J. Boland, *The Evaluation of Drought Management Measures for Municipal and Industrial Water Supply* (Fort Belvoir, VA: Institute for Water Resources, U.S. Army Corps of Engineers, 1983), 1.

Drought Planning and Management Strategies

Drought planning consists of those "actions taken by government, industry, individual citizens, and others in advance of drought for the purpose of mitigating some of the impacts associated with its occurrence."[9] It follows that a key element of drought planning is the identification of specific management strategies. These strategies are delineated according to general types in table 6-1. The first key planning dimension is the time frame; the second is the target of planning actions. In combination, they suggest distinct strategies. A short-term decision process is out-lined in figure 6-2 and a long-term decision process is outlined in figure 6-3. Both are adapted from a U.S. Army Corps of Engineers analysis.[10]

The short-term decision model applies when a crisis is at hand and depends initially on an adequate drought alert system. The alert initiates short-term forecasts of both supply and demand. When a critical shortage is

TABLE 6-1

A TYPOLOGY OF SELECTED DROUGHT PLANNING AND MANAGEMENT STRATEGIES

		Planning Time Frame	
		Short-Term	Long-Term
Target of Planning Actions	Supply	Emergency supplies and conveyance	New supplies and additional storage and conveyance capacity
	Demand	Reduction of use and reduction of losses	Conservation and wise use by suppliers and users

Source: Authors' construct.

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[9] Donald A. Wilhite, "The Role of Government in Planning for Drought: Where Do We Go From Here?" in Wilhite and Easterling, eds., *Planning for Drought*, 439.

[10] Dziegielewski, Baumann, and Boland, *Evaluation of Drought Management Measures*, 18 and 22.

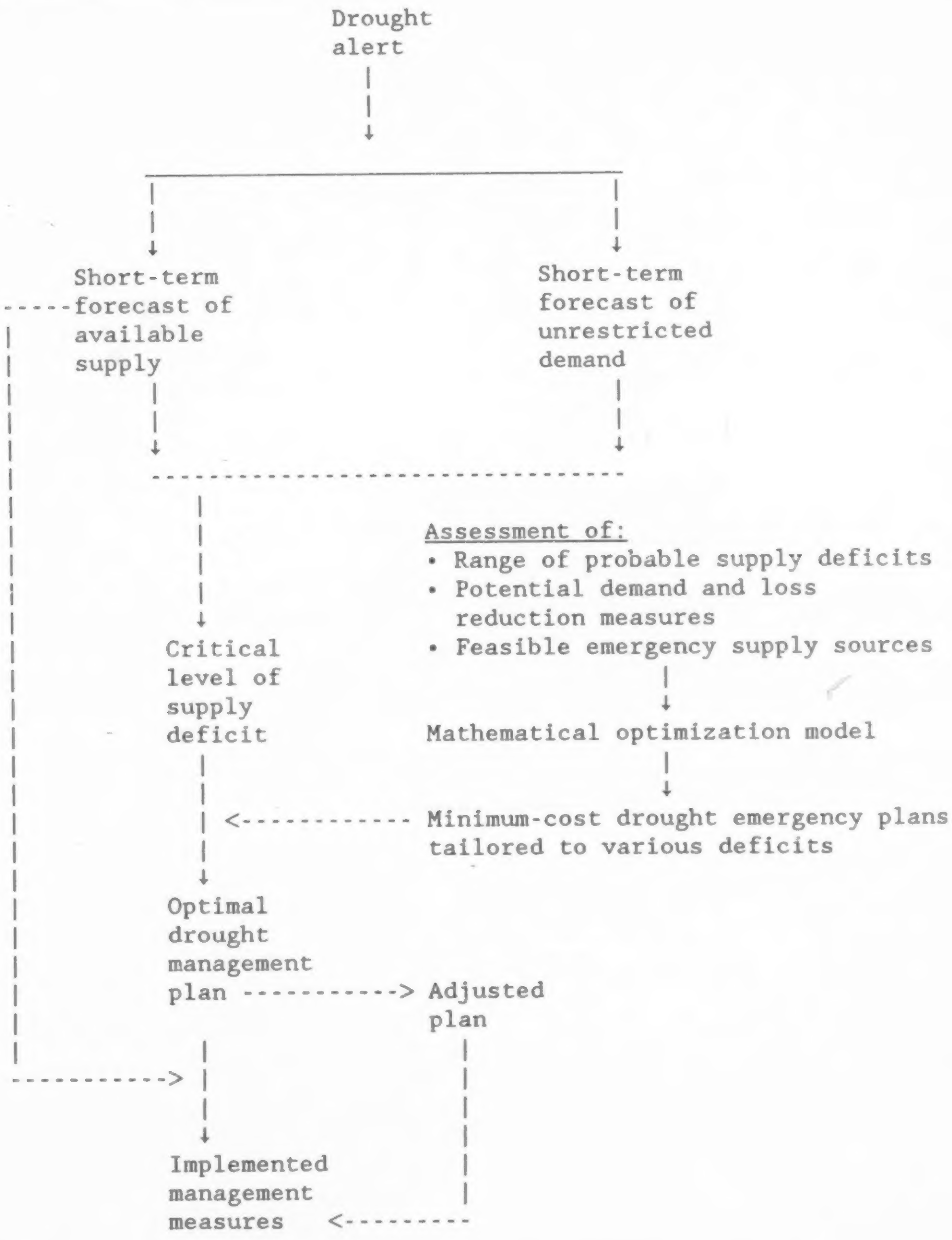
Drought alert
Short-term forecast of available supply
Short-term forecast of unrestricted demand
Critical level of supply deficit
Assessment of:
• Range of probable supply deficits
• Potential demand and loss reduction measures
• Feasible emergency supply sources
Mathematical optimization model
Minimum-cost drought emergency plans tailored to various deficits
Optimal drought management plan
Adjusted plan
Implemented management measures

Fig. 6-2. Short-term drought management decision model as adapted from Benedykt Dziegielewski, Duane D. Baumann, and John J. Boland, *Evaluation of Drought Management Measures for Municipal and Industrial Water Supply* (Fort Belvoir, VA: Institute for Water Resources, U.S. Army Corps of Engineers, 1983), 18 and 22.

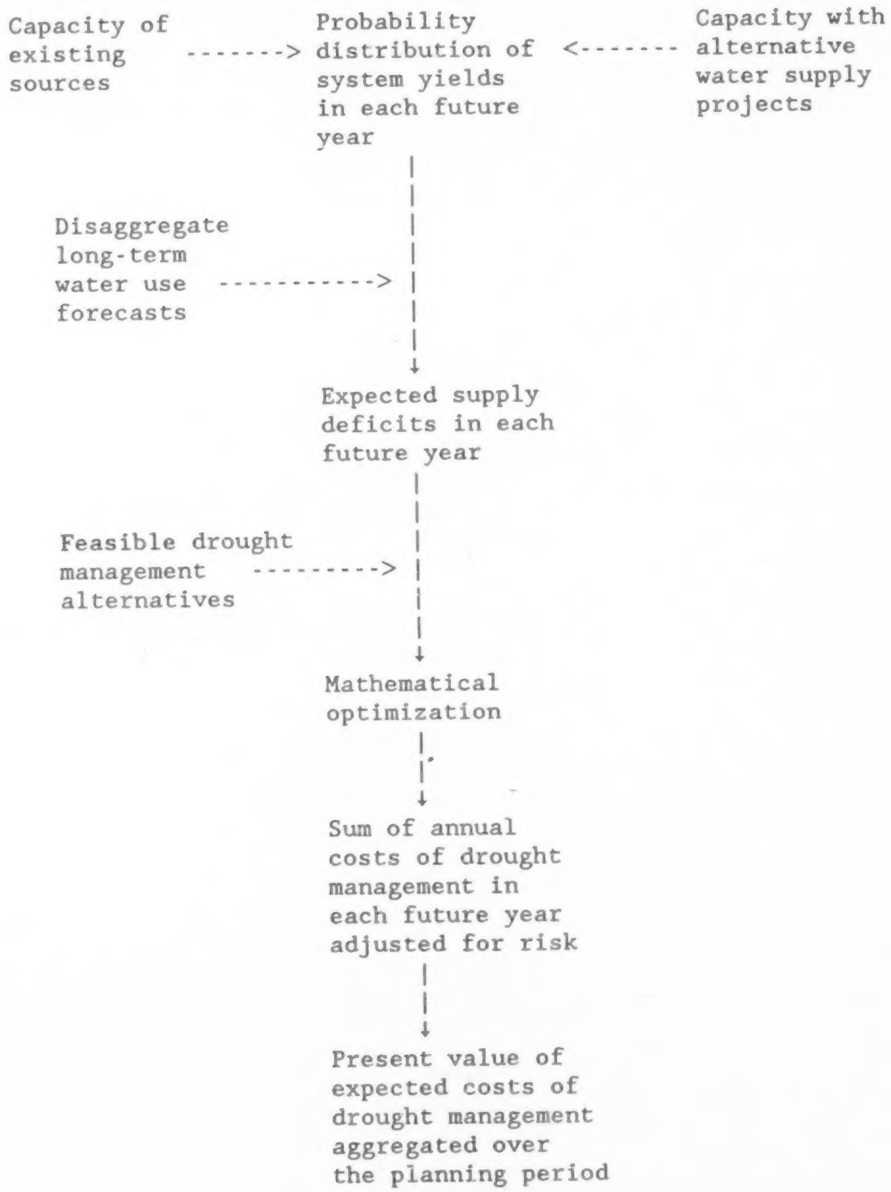
Capacity of existing sources
Probability distribution of system yields in each future year
Capacity with alternative water supply projects
Disaggregate long-term water use forecasts
Expected supply deficits in each future year
Feasible drought management alternatives
Mathematical optimization
Sum of annual costs of drought management in each future year adjusted for risk
Present value of expected costs of drought management aggregated over the planning period

Fig. 6-3. Long-term drought management decision model as adapted from Benedykt Dziegielewski, Duane D. Baumann, and John J. Boland, *Evaluation of Drought Management Measures for Municipal and Industrial Water Supply* (Fort Belvoir, VA: Institute for Water Resources, U.S. Army Corps of Engineers, 1983), 23.

identified, planners must assess the probable supply deficit and ways to mitigate it. A mathematical optimization model may be used to arrive at a minimum-cost drought emergency plan tailored to various deficit scenarios. Once an optimal plan is selected, drought management measures are implemented. Finally, the decision model allows for adjustments to the plan and changes in implemented measures.

The long-term drought management decision model should be a part of a water supplier's long-term planning outlook. It involves an analysis of the probability distribution of system yields in future years, taking into account the capacity of new and existing water supply sources. Disaggregated long-term forecasts are used to predict expected supply deficits in each future year. The feasibility of each drought management alternative is assessed and evaluated in a mathematical optimization model. Finally, the annual cost of drought management is adjusted for risk and the present value of drought management is aggregated for the entire planning period. The result is a long-term plan accounting for both annual and total drought management costs.

Aside from the time frame involved, the other key drought planning dimension is the target of planning actions. Water shortages are caused by an imbalance of supply and demand. In the short-term and the long-term, some strategies target supply while others target demand. Water supply managers need tools to help them choose an appropriate drought management strategy along this dimension. In some cases, a combination of supply and demand measures may be optimal. Table 6-2 illustrates decision processes and assessment criteria for choosing among drought management alternatives. The four steps in the process are: identifying possible measures in both categories, evaluating individual measures, identifying feasible measures, and evaluating their effectiveness.

One possible limitation of drought planning and management decision models is that many do not appear to involve policymakers in the formative stages. For both short-term and long-term models, this may be an important consideration, particularly in view of competing drought management strategies. The following sections review supply and demand alternatives. An expanded review of water conservation and wise use by water suppliers and users in the long term is reserved for chapter 7. An expanded discussion of regulatory and ratemaking issues is contained in chapter 8.

TABLE 6-2

ASSESSMENT OF SUPPLY AND DEMAND ALTERNATIVES FOR MANAGING DROUGHT

	Criteria for Assessment	
Decision Process	Supply Measures	Demand Measures
Identification of Possible Measures	Universe of potential emergency supply sources	Universe of applicable demand and loss reduction measures
Evaluation of Individual Measures	Water availability Water quality Treatment adequacy Construction lead time Construction and O&M costs	Technical feasibility Social acceptability Implementation conditions Effectiveness Implementation costs Economic damages
Identification of Feasible Measures	Feasible emergency supplies	Feasible demand and loss reduction programs
Evaluation of Effectiveness	Available yields and cost parameters	Expected water savings and total costs

Source: Adapted from Benedykt Dziegielewski, Duane D. Baumann, and John J. Boland, *Evaluation of Drought Management Measures for Municipal and Industrial Water Supply* (Fort Belvoir, VA: Institute for Water Resources, U.S. Army Corps of Engineers, 1983), 15.

Water Supply Strategies

Evaluating the feasibility of using emergency supplies during a period of water shortage should take into account a variety of technical and institutional factors. A listing prepared for the Corps of Engineers' analysis points out the importance of careful evaluation when considering the use of emergency water supplies to augment existing supplies. They suggest the use of the following six criteria:[11]

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[11] Ibid., 17.

- The available quantity and quality of water in potential emergency sources.

- The adequacy of existing treatment facilities to produce finished water of acceptable quality when emergency supplies make up some fraction of the raw water supply.

- The lead time required to construct necessary water transmission and pretreatment facilities, if required.

- The construction costs and operation-maintenance costs required to bring emergency sources on line

- The potential legal and institutional considerations involving permits, rights to the source, or easements for transferal systems.

- The foregone benefits associated with cross-purpose diversions of water from alternative uses.

Preparing a list of potential auxiliary water sources in advance of an actual emergency may be an important water management and planning tool. Some of the many types of water supply augmentation are reported in table 6-3. For any particular locality, the choice of emergency supplies may be limited by physical, technological, or economic reasons. Institutional barriers to the development of alternative water supplies, such as those stemming from disputes over water rights, also may be substantial.

Diversions of water from one use to another, for example, may be fraught with conflict stemming from the competition for water, introduced in chapter 1. Frank Welsh noted that the 1976-1977 drought in California illustrated "the perfect paradox of urban and agricultural conservation."[12] In that state, according to Welsh, urban use accounted for only 6 percent of water consumption, compared with 91 percent for agriculture. During the drought, urban areas were forced to reduce consumption by as much as 50 percent. Meanwhile, the acreage in field crops remained virtually unchanged and vegetable, fruit, and nut production actually increased.

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[12] Frank Welsh, *How to Create a Water Crisis* (Boulder, CO: Johnson Books, 1985), 55.

TABLE 6-3

SHORT-TERM AND LONG-TERM STRATEGIES FOR AUGMENTING WATER SUPPLIES

Short-Term Supply Strategies

- Interdistrict transfers
  - Interconnections with other suppliers
  - Importation by truck or railroad from short or long distances
  - Development of regional water conveyance grids
  - Enlargement of conveyance capacity
- Cross-purpose diversions
  - Diversion for alternative uses (hydropower, flood control, recreation)
  - Alteration of stream flow (minimum flow requirements, recharge, downstream users)
  - Relaxation of water quality standards (for diversion to drinking water)
- Auxiliary sources
  - Use of surface waters (untapped creeks, ponds and quarries, dead reservoir storage, temporary pipeline to a river)
  - Use of groundwater (abandoned wells, new wells, mining groundwater)
  - Emergency use of surface waters not usually used for supply purposes
  - Increase of subsurface water supplies
- Intervention and modification of natural processes
  - Cloud seeding
  - Rainfall augmentation
  - Management of snow pack and ice
  - Control of evaporation and evapotranspiration
  - Dew and fog harvesting
  - Reduction of seepage losses
  - Conversion of saline and brackish waters

Long-Term Supply Strategies

- Imports from outside the United States (Canada and Mexico)
- Interstate/interbasin diversions of water
- Weather modification
- Water harvesting/water banking
- Conjunctive use/coordinated groundwater and surface water management
- Desalinization/use of brackish water
- Water reclamation and reuse
- Improving existing project operations
- Better allocation of existing resources
- Groundwater management/recharge

Source: Adapted from Benedykt Dziegielewski, et al., *Evaluation of Drought Management Measures for Municipal and Industrial Water Supply* (Fort Belvoir, VA.: Institute for Water Resources, U.S. Army Corps of Engineers, 1983), 60; Luis Veiga da Cunha, et al., "Use of New and Existing Water Supplies for Coping with Drought," in Vujica Yevjevich, et al., eds., *Coping with Droughts* (Littleton, CO: Water Resources Publications, 1983), 103; and Harvey O. Banks, et al., "Developing New Water Supplies, in Ernest A. Engelbert and Ann Foley Scheuring, eds., *Water Scarcity: Impacts on Western Agriculture* (Berkeley, CA: University of California Press, 1984), 109-25.

Still, the use of irrigation water for drinking water would not be simple to achieve because of the potentially prohibitive costs of diversion as well as treatment to comply with federal and state drinking water standards.

For each potential emergency water source, planners should identify:[13]

- The type of water (surface, ground, purchased)
- Location (distance)
- Drainage area
- Expected water availability (high, low)
- Water quality (good, poor, unknown)
- Possible modes of transportation (pipeline, riverbed)
- Existence of legal and/or institutional obstacles
- Expected costs of transmission
- Other characteristics

An important aspect of drought planning and mitigation is coordination among water service providers. One study of drought responses emphasized that during a drought, neighboring water suppliers have a significant impact on management decisions.[14] Of course, coordination is especially crucial when utilities share water resources or opportunities exist for inter-district transfers during periods of shortage. According to the American Water Works Association, "Joint utility planning in anticipation of a drought should provide for a common approach to drought management among adjacent utilities, identify emergency supplies, and possibly provide for emergency interconnections or other joint actions."[15] To this end, the AWWA recommends that utilities confirm agreements in advance of emergency situations.[16]

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[13] Ibid., 59.

[14] Mark Hoffman, Robert Glickstein, and Stuart Liroff, "Urban Drought in the San Francisco Bay Area: A Study of Institutional and Social Resiliency," in American Water Works Association, *Water Conservation Strategies* (Denver, CO: American Water Works Association, 1980), 81.

[15] American Water Works Association, *Water Conservation Management* (Denver, CO: American Water Works Association, 1981), 51.

[16] Ibid. Three examples of interutility agreements are cited by the AWWA. One is the Potomac River agreement, under which participating agencies adjust their withdrawals to maintain specific flows in the lower reaches of the Potomac River near Washington, D.C. The second is the California exchange agreements that coordinated state, district, and local efforts during the

(Footnote continues on next page)

Supply planning obviously is important. Long lead times for water supply projects and perceptions about water scarcity make this point clear. In some areas, supply augmentation may somehow be prohibited. A plurality of scholars seem to take an integrated view that weighs the advantages and disadvantages of supply management with those for demand management. As John Bredehoeft points out, "It is increasingly difficult to effect major structural changes which would provide large quantities of water to those areas where water is in critical supply. . . . One must turn to other measures to utilize more effectively the water that is currently available."[17] This philosophy is at the heart of demand management and, specifically, water conservation.

Water Demand Strategies

Drought management strategies frequently focus on temporarily reducing water consumption. Sometimes demand management focuses on consumption by the water supplier, and thus may include reductions in water losses through leak detection and repair, and reductions in water pressure. There are limits, however, to the water savings that can be accomplished by suppliers, particularly in the short term.[18] More often, demand management focuses on water users.

Figure 6-4 illustrates the path of decisionmaking for customer-focused demand management during a water shortage. The first major distinction among demand management alternatives is between voluntary and mandatory measures. Obviously, the more severe the shortage, the more likely mandatory measures are to be adopted. Also, drought management is complicated by the fact that voluntary and mandatory measures are sometimes combined.

(Footnote continued from previous page)
drought of the late 1970s and led to the construction of an emergency pipeline connecting Oakland with Marin County. Finally, agreements in Longview, Washington facilitated the supply of water from two paper companies to Longview in the wake of the Mt. St. Helens volcanic eruption.

[17] John Bredehoeft, "Physical Limitations of Water Resources," in Ernest A. Engelbert and Ann Foley Scheuring, eds., *Water Scarcity: Impacts on Western Agriculture* (Berkeley, CA: University of California Press, 1984) 42.

[18] A discussion of conservation by suppliers is reserved for chapter 8.

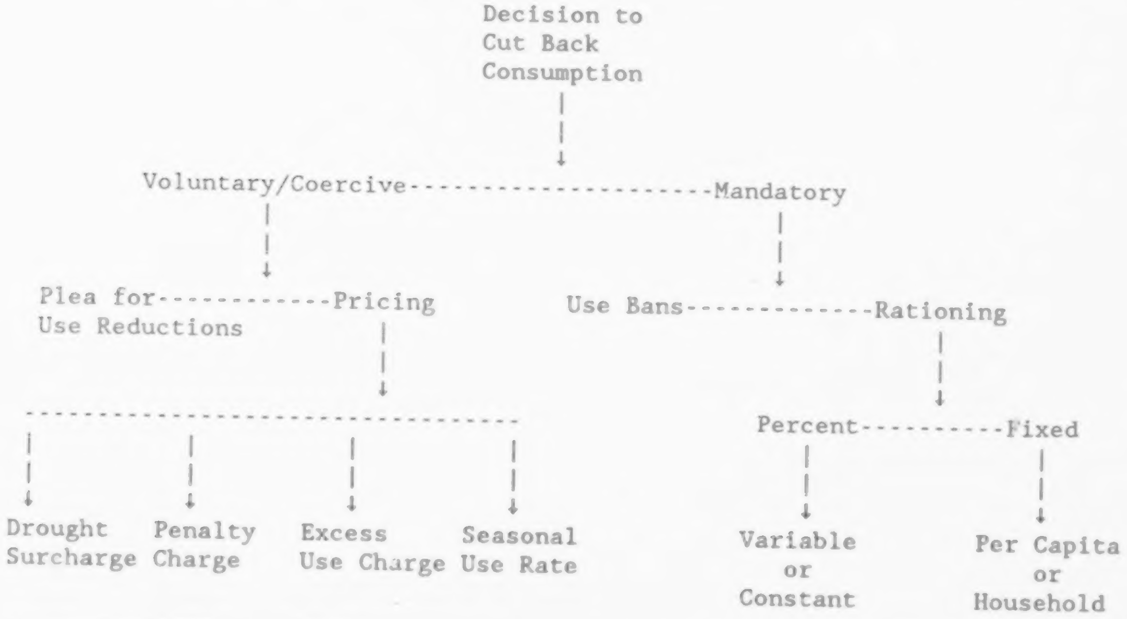
Decision to Cut Back Consumption
Voluntary/Coercive
Mandatory
Plea for Use Reductions
Pricing
Use Bans
Rationing
Percent
Fixed
Drought Surcharge
Penalty Charge
Excess Use Charge
Seasonal Use Rate
Variable or Constant
Per Capita or Household

Fig. 6-4. Demand reduction decision analysis during drought as adapted from Teknekron, Inc., *Urban Drought in the San Francisco Bay Area: A Study of Institutional and Social Resiliency* (Washington, DC: National Science Foundation, 1978).

When a water shortage first becomes apparent, water suppliers often seek voluntary reductions in consumption, at times using somewhat coercive methods. This is often accomplished through a public education campaign through which the supplier pleads for cooperation. Another method for reducing consumption is through pricing. The economic logic of demand dictates that higher prices will cause less consumption. During a drought, water suppliers may choose to impose a drought surcharge, a penalty charge, excess use charge, or a seasonal rate. Water consumption should be reduced more for users or uses with elastic demand. Pricing is a voluntary demand reduction method because those who are willing and able to pay higher prices for water are in a better position to continue consuming what they wish.

Consequently, pricing is a somewhat uncertain method of demand reduction. Changes in pricing practices also can be difficult to implement for political and institutional reasons.[19]

Mandatory demand reduction methods can take the form either of use bans or rationing. Use bans--such as prohibiting lawn watering--often focus on outdoor water use, which is considered less essential. Use bans are fairly simple, although enforcement may be costly. Public education plays an important role in informing water users about the ban and why it is being imposed. Even with a mandatory ban on use, voluntary cooperation remains essential. Rationing is a more complex and more political method of mandatory demand reduction. Rationing can be accomplished by imposing a percentage reduction requirement for users (variable or constant) or by setting a fixed amount of allowable use (per capita or per household).

The American Public Works Association compiled a series of studies on the effectiveness of usage bans and rationing implemented between 1967 and 1978, as reported in table 6-4. Decreases in consumption ranged from 10 to 63 percent. Naturally, voluntary programs yield more limited water savings, although a 20 percent savings is still significant. Rationing with fines, however, appears to be highly effective in curtailing consumption.

Some analysts believe that although droughts are intermittent experiences, the demand reduction measures implemented during a drought may have lasting effects. Efficiency gains by suppliers and users are not automatically undone after a drought is over. In fact, according to one study, "It is a reasonable assumption that residential water demands in future years will not be represented (if they ever were) by linear trends which treat pre-drought consumption levels as a relevant basis for projection."[20] Thus, the drought experience should be analyzed and taken into account in terms of potentially permanent effects on water consumption patterns.

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[19] Pricing and elasticity are discussed in detail in chapter 8.

[20] Frank H. Bollman and Melinda A. Merritt, "Community Response and Change in Residential Water Use to Conservation and Rationing Measures: A Case Study--Marin Municipal Water District," in James E. Crews and James Tang, eds., *Selected Works in Water Supply, Water Conservation and Water Quality Planning* (Fort Belvoir, VA: Institute for Water Resources, U.S. Army Corps of Engineers, 1981), 393.

TABLE 6-4

DROUGHT MANAGEMENT MEASURES AND THEIR IMPACT ON DEMAND REDUCTION

Investigator	Location	Year	Restriction Imposed	Resulting Decrease
R. W. Anderson	Pawtucket, Rhode Island	1967	Ban on outside use; appeals.	16-18%
Groopman	New York City	1968	Ban outside use; appeals.	10-22%
Abbott, et al.	17 Eastern utilities	1972	Voluntary and compulsory bans on outside use; appeals.	18-50%
Jezler	Sao Paulo, Brazil	1975	Ban on outside use; limits on household use.	26%
E.A.I.	Washington Suburban Sanitary Commission	1977	Ban on outside use; appeals to specific acts.	40%
Bollman	Marin County, California	1977	Ban on outside use. Rationing with fines.	25% 63%
National Water Council	Great Britain	1976	Ban on outside use.	25%
D. G. Larkin	Oakland, California	1978	Rationing with fines.	38%
Miller	Denver, Colorado	1978	Limit outside use to three hours every third day.	21%
Griffith	Los Angeles, California	1978	Appeals; limited industry cutbacks with some mandatory controls.	10-20%
Robie	California	1978	Voluntary. Rationing.	up to 20% up to 50%

Source: American Public Works Association, *Planning and Evaluating Water Conservation Measures* (Chicago: American Public Works Association, 1981), 23.

The effectiveness of demand management may depend in part on the demographic and housing characteristics of the service population, as revealed in a study of water consumption in 1976 and 1977 by customers of the Marin Municipal Water District by Frank H. Bollman and Melinda A. Merritt.[21] Bollman and Merritt found that water consumption increased with both household size and income. Higher incomes are associated with higher property values, larger house lots requiring water, more water-using appliances, and swimming pools. All of these factors add up to more water consumption.

As reported in table 6-5, under normal conditions, one-third of the variance in water use could be collectively explained by the following variables: household size (15.2 percent), lot size requiring water (11.7 percent), swimming pools (4.5 percent), and income (3.1 percent). When rationing to 75 percent of normal usage, both household size and lot size remain important in explaining total consumption. However, under more stringent rationing, to 43 percent of normal, household size stands out as the most important determinant of variation in water use. The study confirms the intuitive notion that during rationing, basic needs that correlate with household size determine water consumption while lawn watering and other outdoor uses decline. In fact, the data suggest that income is far less important than household size in determining consumption. When rationing was imposed, households with higher incomes reduce their water consumption in proportions comparable to those of lower incomes.

In addition to demographic factors, public attitudes may make or break a demand management program. Mark Hoffman, Robert Glickstein, and Stuart Liroff assessed eight programs implemented by California water systems during the 1977 drought.[22] They found that the imposed rationing plans far exceeded expectations in reducing water consumption during the drought. The authors emphasized the importance of the public's "belief" in the drought because of its effect on their cooperation: "Research indicates that the willingness of residential, and to a lesser extent commercial and

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[21] Bollman and Merritt, "Community Response and Change" in Crews and Tang, eds., *Selected Works in Water Supply*.

[22] Hoffman, Glickstein, and Liroff, "Urban Drought in the San Francisco Bay Area," in American Water Works Association, *Water Conservation Strategies*.

TABLE 6-5

DETERMINANTS OF HOUSEHOLD WATER CONSUMPTION

	Percent of Variance Explained *		
Determinant of Water Consumption	Normal Use (1975)	Rationed to 75% of Normal Use (1976)	Rationed to 43% of Normal Use (1977)
Household size	15.2%	21.9%	34.1%
Lot size requiring water	11.7	10.1	1.2
Swimming pool	4.5	4.5	2.7
Income	3.1	3.1	1.2
Total percent of variance explained by these factors	34.5%	39.6%	39.2%

Source: Frank H. Bollman and Melinda A. Merritt, "Community Response and Change in Residential Water Use to Conservation and Rationing Measures: A Case Study--Marin Municipal Water District," in James E. Crews and James Tang, eds., *Selected Works in Water Supply, Water Conservation and Water Quality Planning* (Fort Belvoir, VA: Institute for Water Resources, U.S. Army Corps of Engineers, 1981), 391.

* For each of the years, the F-ratio generated by the multiple r-squared from the regression equation was significant at the .01 level.

industrial, customers to restrict their water consumption is influenced more by the degree to which they believe there is a shortage requiring conservation than by any other factor."[23] Interestingly, large-scale reductions in usage can be achieved even when a water system's rationing plan is perceived as unfair by more than 50 percent of its customers, leading the authors to conclude that, "once the public is convinced that there is a shortage, they will conserve whether they feel the rationing plan is fair or not."[24]

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[23] Ibid., 82.
[24] Ibid., 83.

Thus, the effectiveness of demand management programs during droughts may depend on consumers' responsiveness, which in turn appears to depend on a variety of factors, as identified elsewhere.[25] Consumers may need to be convinced that an actual water shortage exists and that it poses a problem for them as a group. They may need to be convinced that their individual efforts can make a difference in the collective welfare of the group and that others are making a sincere effort to conserve as well. They also may need to be convinced that the costs and inconveniences associated with conservation will be small, assuming this is true. Finally, the cooperation of consumers may depend on the appeal to moral principles, stressing the need for each member to make a fair contribution to the group's welfare. Perceptions of bad faith may cause the downfall of even the most well-designed conservation program.

Drought Planning by Water Suppliers

Virtually all water suppliers at one time or another will experience a water shortage due to drought or some other artificial or natural cause. It is imperative, therefore, that each have a drought contingency plan, as most probably do. Some, however, may require revision in light of contemporary supply parameters and policy alternatives.

Every drought plan should include a logical progression of actions to mitigate the effects of a water shortage. The plan might be calibrated to an empirical measure of drought conditions, such as the Palmer Drought Index (PDI) or measures of a water system's capacity. Its progression should reflect the priorities that will guide water supply managers in their response to drought conditions. Ideally, the plan should identify, in advance of a crisis, the water uses that have high priority and the water uses that have low priority. It should also address the potential equity problems that may arise under the plan and ways to mitigate them. In addition, it should follow certain broad planning principles, such as those discussed below.

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[25] Richard A. Berk, et al., *Water Shortage: Lessons in Conservation from the Great California Drought, 1976-77* (Cambridge, MA: Abt Books, 1981), 148.

Guiding Principles in Drought Planning

Drought planning, indeed any planning process, is enhanced by the development of guiding principles, particularly when derived from actual experience. The American Water Works Association developed several case studies of drought planning based on the actions taken by selected New England communities that were used to identify some of the important guidelines for water systems engaged in drought planning.[26] These principles are:

- Maintain credibility by providing consistent information, coordinated education efforts, and programs that proceed without major changes.
- Set an example for efficient water use.
- Reserve crisis-type emergency programs for a genuine crisis.
- Use accurate data on conditions and implement comprehensive monitoring.
- Develop a drought contingency plan to improve efficiency.
- Update drought contingency plans regularly rather than only during a drought or emergency.
- Develop a comprehensive public education program.
- Teach water users how to conserve.
- Include the actions necessary to acquire the legal authority and permits necessary to implement programs in the drought contingency plan.
- Maintain good working relationships with local government officials, possibly through the formation of a drought task force.
- Enlist a well-respected person to represent the utility and its program.

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[26] The observations that follow are from American Water Works Association, *Before the Well Runs Dry: Volume II--A Handbook on Drought Management* (Denver, CO: American Water Works Association, 1984), 42-43.

- Include a mandatory use-reduction program in the later stages of the drought contingency plan.

- Target individual users in the system, especially industrial users.

- Shut off services to nonessential business and industries only when there is a clear and imminent threat to community health and safety to reduce liability for economic losses.

- Make use of federal research and demonstration programs and state resources in the areas of planning and technical assistance, coordination of local programs, and rate approvals by public utility commissions.

The development of a drought contingency plan is an essential part of this framework. The key, of course, is that the plan be prepared before drought conditions materialize and structured to assist water supply managers deal with different levels of drought severity.

Sample Drought Contingency Plans

A sample contingency plan for a water shortage published by the American Water Works Association (AWWA) is reported in table 6-6.[27] It consists of four drought stages: minor, moderate, severe, and critical. For each, a demand reduction goal is identified ranging from 10 percent to 50 percent or more. Drought responses are organized according to public information actions, public sector actions, user restrictions, and penalties. In the early stages, the emphasis is on public education and voluntary use reduction. As conditions worsen, mandatory restrictions are imposed. As a last resort, water pressure is reduced and water service may be terminated for some users. Penalties for noncompliance are specified under the plan. In cases where violations are repeated, enforcement may require more severe penalties. In table 6-7, possible penalties for

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[27] American Water Works Association, *Water Conservation Management* (Denver, CO: American Water Works Association, 1981), 45.

TABLE 6-6

AMERICAN WATER WORKS ASSOCIATION'S SAMPLE CONTINGENCY PLAN FOR A WATER SHORTAGE

Stage	Drought/ Emergency Condition	Consumption Reduction Goal (percent)	Public Information Action
I	Minor	10	Explain drought/emergency conditions. Disseminate technical information. Explain other stages and possible actions. Distribute retrofit kits at central depots. Request voluntary reduction.
II	Moderate	15 to 18	Use media intensively to explain emergency. Explain restrictions and penalties. Explain actions in potential succeeding stages. Request voluntary reduction.
III	Severe	25 to 30	Public officials appeal for water use reduction. Explain actions and consequences of emergency.
IV	Critical	50 or more	Same as III.

TABLE 6-6--Continued

Stage	Public Sector Action	User Restrictions	Penalties
I	Increase enforcement of hydrant opening regulations. Increase meter reading efficiency and meter maintenance. Intensive leak detection and repair program.	Voluntary installation of retrofit kits. Restriction of outside water use for landscape, washing cars, and other uses.	Warning
II	Reduce water usage for main flushing, street flushing, public fountains, and park irrigation.	Mandatory restriction on all outside uses by residential users except landscape irrigation. Prohibit unnecessary outside uses by any commercial users.	1-Warning 2-House call 3-Installation of flow restrictor 4-Shut off and reconnection fee
III	Prohibit all public water uses not required for health or safety.	Severely restrict all outside water use. Prohibit serving water in restaurants. Prohibit use of water-cooled air conditioners without recirculation.	Same as Stage III
IV	Reduce system pressure to minimum permissible levels. Close public water using activites not required for health or safety.	Prohibit all outside water use and selected commercial and industrial uses. Terminate service to selected portions of system as last extreme measure.	Same as Stage III

Source: American Water Works Association, *Water Conservation Management* (Denver, CO: American Water Works Association, 1981), 45.

TABLE 6-7

POSSIBLE PENALTIES FOR NON-COMPLIANCE WITH DEMAND MANAGEMENT MEASURES DURING A DROUGHT

Violation occurrences	Violation	
	Prohibited uses	Excess uses
First	Written warning via regular mail.	Written warning via regular mail.
Second (a)	Written warning delivered by a utility representative who will offer conservation tips and approved retrofit devices.	Surcharge if allowed use level is exceeded.(b) Written warning delivered by a utility representative who will offer conservation tips and approved retrofit devices.
Third (a)	Flow restrictor (1 gpm) installed for 48 hours. Installation and removal charges assessed.	Surcharge if allowed use level is exceeded. Flow restrictor (1 gpm) installed for 48 hours. Installation and removal charges assessed.
Additional (a)	Shutoff, plus a reconnection charge.	Surcharge if allowed use level is exceeded. Shutoff, plus a reconnection charge.

Source: Adapted from William O. Maddaus, *Water Conservation* (Denver, CO: American Water Works Association, 1987), 80.

(a) Within one year of first occurrence.
(b) The source suggests the imposition of a surcharge when the "carryover of savings" is negative.

noncompliance with a drought plan for prohibited uses and excess uses are described.

An example of an actual drought contingency plan triggered by capacity levels and tailored to the characteristics of the water system is reported in table 6-8. The plan was developed for Manchester, Connecticut. Each stage of the plan is tied to capacity and each action is geared toward a certain yield. Public education begins in the drought watch period before further management action is required. In the first stage, water supply managers have options which narrow as conditions grow more serious. In the last stage, withdrawals from one of the system reservoirs is discontinued altogether. In a severe drought, the provisions of the plan are expected to save 2.7 million gallons daily.

Complex drought management strategies, such as Manchester's, combine mandatory prohibitions on use with higher water prices designed to enlist voluntary use reductions. The experience of the Marin Municipal Water District, a public retail water supplier, during the 1975-1976 drought in California illustrates the progressive use of various demand management measures (including rate hikes) over twenty months, as reported in table 6-9. Eventually, water rationing was imposed through usage allotments. A study of the District and its drought management concluded that the experience caused permanent reductions in water consumption.[28]

Many public utility commissions may be in a position to review the drought contingency plans of their jurisdictional water utilities. Model plans, such as that designed by the AWWA, provide a useful perspective on the types of considerations that contingency plans should address. A statewide review of plans can facilitate coordination among water suppliers and possibly help avoid conflict over scarce water resources when droughts or other forms of water shortage occur.

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[28] Bollman and Merritt, "Community Response and Change in Residential Water Use to Conservation and Rationing Measures," in Crews and Tang, eds., *Selected Works in Water Supply*.

TABLE 6-8

DROUGHT CONTINGENCY PLAN FOR MANCHESTER, CONNECTICUT

Drought Watch

When water levels are at 70% of normal seasonal capacity.

1. Periodic announcements alerting the public to the depletion of storage in the reservoirs, current meteorological conditions, and long-range outlook from the National Weather Service.

2. Alert the public to the possibility of implementing sequential sets of emergency measures.

Stage 1

When water levels are at 57% of normal seasonal capacity, cut back withdrawals from reservoirs by 5% or reduce total south system use by 3.8%.

Option 1 Leak detection and repair *(.15 mgd yield or 5%)*

Option 2 Limited mandatory use restrictions *(.11 mgd savings or 3%)*
- alternate day sprinkling/outdoor use hour restrictions
- pool filling by permit only
- restaurants serve water by request only
- change plumbing code

Option 3 Education *(.1 mgd savings or 3%)*
- newsletters
- bill inserts
- reminder items
- press releases

Stage 2

When water levels are at 40% of normal seasonal capacity, reduce withdrawals from south system reservoirs by about 30% or reduce total south system use by 20%.

1. Continue Stage 1 savings of .1 mgd (3%)

2. Revise rate: drop minimum use per billing period, raise rate to $1.00 per 100 cu. ft. for first two blocks
   .15 mgd savings (5%); revenue increase

3. Fixture distribution and education program savings
   .21 mgd (7%)

4. Complete outdoor use ban, add .1 mgd savings if partial outdoor use ban in effect or total
   .21 mgd (7%)

TABLE 6-8--Continued

Stage 2 (continued)

5. Implement leak detection and repair, if not already done in Step 1
   .15 mgd (5%)

TOTAL SAVINGS: .6 to .7 mgd (20%)

Stage 3

0% of normal seasonal capacity, reduce withdrawals from south system reservoirs by 100%, reduce total south system use by 70%

1. Ration residential users to 45 gpcd, require approximately 10% reductions by commercial, industrial, and municipal users
   savings: .875 mgd residential
   .085 mgd commercial/industrial/municipal
   .96 mgd total (30%)

2. Leak detection and repair from Stage 2
   yield: .15 mgd (5%)

3. Connect north-south system
   yield: 1.6 mgd (50%)

4. Continue education and fixture distribution programs to assist users in reducing use - no additional savings

TOTAL SAVINGS: 2.7 mgd

Source: American Water Works Association, *Before the Well Runs Dry: Volume II--A Handbook on Drought Management* (Denver, CO: American Water Works Association, 1984), 36.

TABLE 6-9

DROUGHT RESPONSES BY THE MARIN MUNICIPAL WATER DISTRICT, 1975-1976

Effective Date	Rate (per 100 cu. ft.) Previous	Rate (per 100 cu. ft.) New	Water Use Restrictions/ Penalties
February 11, 1976	---no change---		Prohibition of waste, nonessential uses (gutter flooding). Disconnection of service after two warnings.
March 1, 1976	$ .46	$ .61	Regular rate. Prohibition of nonessential uses: 1. Sprinkler systems: hand-held hose only. 2. Washing or hosing of hard-surfaced areas and motor vehicles except with 3 gallon container. Disconnection of service after two warnings.
April 28, 1976	---no change---		Prohibition of filling any swimming pool emptied on or after April 29.
July 28, 1976	.61	.61/.84	Two-step (peak load) residential rate structure: .61 up to bimonthly usage established for the 5 residential classes. .84 for water usage in excess of these usages.
July 28, 1976	---no change---		Filling of any new swimming pool prohibited.
February 1, 1977	.61/.84	1.22	Regular rate. Penalty rate structure: $10.00 per 100 cu. ft. used in excess of allotments--up to twice said allotment. $50.00 per 100 cu. ft. in excess thereof.

TABLE 6-9--Continued

Effective Date	Rate (per 100 cu. ft.) Previous	New	Water Use Restrictions/ Penalties
February 1, 1977	---no change---		a) Bimonthly usage allotments established for each class of water user. b) Noncompliance to result in service disconnection and installation of flow restrictor. c) General Manager may grant variances or adjust allotments.
June 1, 1977	---no change---		Bimonthly usage allotment to nonresidential users increased.
July 1, 1977	---no change---		Rules for termination of service eased.
August 1, 1977	1.22	1.34	Regular rate.
October 1, 1977	1.34	1.87	For consumption over 400 cubic feet an additional $.53 per cubic feet pipeline charge is levied to pay for pipeline conveying water across the Richmond-San Rafael Bridge.

Source: Frank H. Bollman and Melinda A. Merritt, "Community Response and Change in Residential Water Use to Conservation and Rationing Measures: A Case Study--Marin Municipal Water District," in James E. Crews and James Tang, *Selected Works in Water Supply, Water Conservation and Water Quality Planning* (Fort Belvoir, VA: Institute for Water Resources, U.S. Army Corps of Engineers, 1981), 377-78.

TABLE 6-10

CHRONOLOGY AND SUMMARY OF SELECTED DROUGHT MANAGEMENT STUDIES, 1961-1981

Community or Water District	Year	Reported Drought Management Actions	Other Information
New York	1961-1965	Water use restrictions, acquiring emergency supplies.	Political aspects.
48 Massachusetts communities	1962-1966	Restrictions, price adjustment, meter adjustment, leak survey/repairs, provision of emergency supplies, new sources, improvements in present supply, cloud seeding.	Comprehensive analysis of all aspects of water supply in relation to drought, including determination of losses.
New York water system	1965	Restrictions on outside use, mass media appeals.	Effectiveness estimates.
City of Pawtucket Water District, Rhode Island	1965-1966	Voluntary conservation, ban on nonessential uses, ban on use of water for air conditioning.	Conservation effectiveness.
York, Pennsylvania	1966	Voluntary restrictions, ban on the use of water hoses, ban on car washing, use of water-cooled air conditioners, filling of swimming pools, serving water in restaurants, customer education, 26 water imports by trucks.	Methodology for estimating economic losses from water shortage including computer simulation program.
30 districts and communities in 9 California counties	1976	Metering, conservation education, retrofit kits, water recycling, plumbing code changes, restricted outside use, warnings and citations, service shutoffs, rationing, water rate surcharge, prohibitions on new connections, other.	Time-series data from over 50 districts on water use and conservation activities.
35 major urban areas in California (MMWD, EBMUD)	1976-1977	Voluntary and mandatory restrictions, public awareness programs, use of reclaimed water for irrigation, temporary pipeline.	Overview of drought-related activities of DWR.

TABLE 6-10--Continued

Community or Water District	Year	Reported Drought Management Actions	Other Information
NMCWD in California and 11 other utilities	1976-1977	Various types of rationing programs	Cumulative savings in water use
8 San Francisco Bay Area utilities: SFWD, EBMUD, CCCWD, MMWD, and others	1976-1977	Emergency surface supplies, dead storage, new wells, leak detection, interdistrict transfers, cross-purpose diversion, voluntary and mandatory restrictions.	Data on demand reduction and supply augmentation costs to the districts.
Metropolitan Water District of Southern California	1976-1977	Voluntary conservation, educational program, a rate surcharge, mandatory rationing.	Effectiveness of conservation programs.
EMBUD district in California	1976-1977	Rationing plan, prohibitions against wasteful usage, rate increase, excess use charge, educational campaign, new supply source, leak detection and repair.	None specified.
25 municipalities in Illinois	1976-1977	Voluntary restrictions, ban on outdoor usage, rationed industrial/commercial use, rate adjustment, rationing to residential users.	Questionnaire survey data.
62 towns in Colorado	1976-1978	Obtained short-term surface water sources, trucked in water, changed points of diversion, cleaned out and repaired water mains, restrictions: alternate day sprinkling, sprinkling bans, prohibitions of outdoor uses, rationing, raised water rates.	Documentation and analysis of drought responses (questionnaire survey).
12 Iowa communities	1977	Mandatory and voluntary restrictions.	Results of personal interviews with policymakers.

TABLE 6-10--Continued

Community or Water District	Year	Reported Drought Management Actions	Other Information
Denver Water Department, Colorado	1977	Tap allocation (new connections), public information program on water conservation.	Conservation effectiveness, revenue losses.
Hackensack WC, City of Newark	1980	2.5-mile overland pipeline, and other emergency supply sources.	Cost of temporary facilities, lead time.
24 Missouri Water Suppliers	1980	Voluntary conservation, mandatory bans on nonessential uses.	Survey data.
8 Communities in Illinois	1980-1981	Voluntary and mandatory restrictions, new water sources, rate adjustment.	Expenses on drought management measures.

Source: Benedykt Dziegielewski, Duane D. Baumann, and John J. Boland, *Evaluation of Drought Management Measures for Municipal and Industrial Water Supply* (Fort Belvoir, VA: Institute for Water Resources, U.S. Army Corps of Engineers, 1983), 9-13.

Evaluations of Drought Management

Researchers have investigated the effectiveness of drought management in great depth. Table 6-10 reports a series of drought responses across the nation from the late 1960s to the early 1980s compiled by the Corps of Engineers.[29] Both supply and demand strategies were used and many water systems used more than one type of measure. Most were traditional strategies, such as mandatory and voluntary user restrictions. Despite the obvious responsiveness of each system to drought conditions, the Corps analysis suggests room for improvement:

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[29] Dziegielewski, Baumann, and Boland, *The Evaluation of Drought Management Measures*.

> Although many drought management programs were quite sophisticated, each of them were of an ad hoc nature. The measures introduced to conserve dwindling water supplies were selected based on logic, experience and a sense of values rather than the known monetary and non-monetary impacts that they have on water users and the community itself.[30]

Compared with ad hoc methods, which reflect crisis management, a risk management approach to drought planning emphasizes setting priorities in advance of a water shortage based on assessments of likely impacts. Of course, this takes a considerable amount of effort on the part of water suppliers and, perhaps, their regulators.

Absent planning, priorities in drought management may be far more informal than formal. In a useful study of this issue, water managers in Massachusetts were interviewed about their perceptions of drought as well as their preferred course of action in response to drought conditions over time.[31] On average, water managers implement their first "drought adjustment" about six months after recognizing the drought condition, although some may take as long as two years.

In their first adjustment to the drought, the alternative preferred by most managers--in twenty-five of thirty-nine cases--was to reduce water demand by imposing either voluntary or mandatory restrictions on use. A smaller number (twelve) would first choose to augment supplies on either an emergency or a permanent basis. Only two of the thirty-nine managers in the study would first choose pricing or metering to alter demand. In the second adjustment to drought, the emphasis shifts to augmenting water supplies. In the third adjustment, the emphasis shifts to demand modification as well as supply planning from an engineering perspective. The authors conclude that water supply managers have a solid preference for a few traditional strategies and that expanding their knowledge of alternatives would be "exceedingly useful."

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[30] Ibid., 8.

[31] Clifford S. Russell, David G. Arey, Robert W. Kates, *Drought and Water Supply: Implications of the Massachusetts Experience in Municipal Planning* (Baltimore, MD: Johns Hopkins Press, 1970), 81-83.

TABLE 6-11

HYPOTHETICAL COST COMPARISON OF DROUGHT MANAGEMENT ALTERNATIVES

Program		Drought Management Measure(s)	Water Reduction Effectiveness(a)		Adjusted Cost(b)	
			MGD	Pct.	Lump Expense	Monthly Cost
1	M1	Pressure reduction by 10 psi in entire distribution system	0.6	3%	--	--
2	M2	Voluntary curtailment of lawn watering by residential customers	1.0	5	--	5,000
3	M3	Water conservation kits made freely available to domestic users at central locations	1.0	5	60,000	--
4	M4	Educational campaign encouraging all customers to conserve water	1.6	8	12,000	5,000
5		M2 and M4	2.2	11	12,000	8,000
6		M1, M2, and M4	2.6	13	12,000	8,000
7	M5	Leak detection and repair program	3.0	15	15,000	8,000
8	M6	Water conservation kits distributed and installed by utility crews upon customer's permission	3.0	15	60,000	8,000
9	M7	Enforced restrictions on car washing, pool filling, golf courses, and landscape irrigation	3.0	15	--	20,000
10		M1, M2, M3, and M4	3.6	18	72,000	8,000
11	M8	Introducing emergency water with surcharge (50%) to penalize excessive users	5.0	25	--	50,000
12		M3, M4, M5, and M6	6.0	30	87,000	13,000
13	M9	Rationing by fixed allocation of 40 gpcd in all households with penalties for non-compliance	8.0	40	--	80,000
14		M1, M4, M7 and M8	8.0	40	12,000	75,000

TABLE 6-11--Continued

Program	Drought Management Measure(s)	Water Reduction Effectiveness(a) MGD	Water Reduction Effectiveness(a) Pct.	Adjusted Cost(b) Lump Expense	Adjusted Cost(b) Monthly Cost
15	M10 Ban on all non-essential uses with strict enforcement	12.0	60	--	200,000
16	M1, M4, M5, M6, M7, and M9	12.0	60	87,000	165,000
17	M1, M4, M5, and M10	15.0	75	27,000	200,000

Source: Adapted from Benedykt Dziegielewski, Duane D. Baumann, and John J. Boland, *Evaluation of Drought Management Measures for Municipal and Industrial Water Supply* (Fort Belvoir, VA: Institute for Water Resources, U.S. Army Corps of Engineers, 1983), 56-57. Data have been reorganized to appear in ascending order according to potential water savings.

(a) Effectiveness of each conservation measure is summed for all sectors that are affected by the measure. Percentage reductions are based on 20 mgd.
(b) Costs include implementation costs, economic losses to customers, and monthly costs if the measure is in effect; "--" indicates negligible costs.

Another study found that, "When formulating drought policies, and especially rationing programs, water district officials placed far greater weight on the equity and public perception of the respective programs than on administrative convenience and revenue considerations."[32] The findings suggest that droughts may have a significant and potentially long-lasting effect on decisionmaking dynamics.

The Corps of Engineers recommends that water supply managers carefully evaluate the effectiveness and cost of alternative drought mitigation measures and to strive for an optimal balance of supply and demand measures. Managers should evaluate measures individually as well as in combination so that they may have a better understanding of alternative drought management programs.

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[32] Hoffman, Glickstein, and Liroff, "Urban Drought in the San Francisco Bay Area," in American Water Works Association, *Water Conservation Strategies*, 81.

A hypothetical analysis of the effectiveness and costs of a series of management strategies is presented in table 6-11. The entries are arranged in ascending order based on the level of expected water savings. The findings indicate that limited savings (3 percent) can be achieved through pressure reduction. Certain voluntary demand reduction measures are actually more effective, but they also cost more. This type of analysis is particularly useful in evaluating alternative methods for achieving comparable goals. For example, the table identifies three very different methods for achieving a 15 percent reduction in demand, two methods for a 40 percent reduction, and two methods for a 60 percent reduction. According to the analysis, savings of up to 75 percent during a severe water shortage are possible, although with a considerable price tag. Thus a cost-effectiveness analysis can be a key part of a water supplier's drought management strategy, in lieu of ad hoc decisionmaking processes.

Certainly one area in which droughts should have a lasting effect is in drought planning. With each water shortage episode, water supply managers gain in knowledge and experience that should be applied to future planning efforts. The planning also should extend to those government agencies with regulatory authority over water suppliers, including state public utility commissions. Most drought contingency plans require the cooperation, and in some cases the approval, of government agencies for certain actions. Because public support is also essential to the effectiveness of drought mitigation, it also makes sense to include representatives of the public in the planning process. All of these efforts will move drought responsiveness away from crisis management and toward risk management, away from reactive measures and toward anticipatory ones. This shift in emphasis also is consistent with the wise-use-of-water perspective.

Droughts can be planned for as well as managed. However, governments and the public are concerned not only with short-term drought mitigation but with long-term strategies for coping with water shortages or for avoiding them altogether. The next chapter focuses on conservation and the wise use of water as long-term planning strategies.

CHAPTER 7

CONSERVATION AND THE WISE USE OF WATER

As noted in one study, "Few actions are as mindless as turning on the water tap."[1] Conservation and other wise-use approaches advocate the view that the use of water should be an action that is informed and purposive, not reflexive and mindless. Wasteful use, in particular, is a target of conservationist efforts.

Many different rationales are available for promoting water conservation, as reviewed in chapter 1. Some view conservation as a means of preserving and protecting a natural resource. Others emphasize avoiding the waste and degradation of water resources by mankind. Still others recognize conservation as a way to deal with impending water scarcity as demand approaches the limits of available supply on a regional or even a global basis. Thus, conservation is a wise-use strategy for dealing with water scarcity in the long term. As also noted in chapter 1, many activities qualify as conservation. Table 7-1 summarizes some typical conservation strategies; for further reference, a comprehensive listing appears in appendix B. Although this chapter focuses on conserving public supplies, the potential for conservation in agriculture and industry to reduce total demand and make more water available for public use is an important consideration as well.

Conservation measures generally fall into one of several categories, as depicted in table 7-2. Some actions target efficient use of supplies while others target demand reduction. Further, both supply and demand management strategies can be distinguished according to whether the water supplier or the water user is the managing agent.

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[1] William E. Martin, et al., *Saving Water in a Desert City* (Washington, DC: Resources for the Future, 1984), 6.

TABLE 7-1

SELECTED LONG-TERM WATER CONSERVATION STRATEGIES

General Application
- Public education
- In-school education
- Metering
- Pressure reduction
- Pricing
  - Uniform commodity rate
  - Increasing commodity rates
  - Seasonal rates
- Leak detection and repair
- System rehabilitation

Interior Residential Use
- Low-flow shower heads
- Shower-flow restrictors
- Toilet-tank displacement bottles/tanks
- Pipe insulation
- Faucet aerators
- Water-efficient appliances

Devices for New Construction
- Low-flush and ultra-low-flush toilets
- Low-flow shower heads
- Pipe insulation
- Faucet aerators
- Water-efficient appliances

Power Generation
- Recirculation of cooling water
- Reuse of treated wastewater
- In-system treatment

Industrial Use
- Recirculation of cooling water
- Reuse of cooling and process water
- Reuse of treated wastewater
- Efficient landscape irrigation
- Low-water-using fixtures
- Process modification

Agricultural Irrigation
- Off-farm conveyance systems
  - Canal lining, realignment, and consolidation
  - Phreatophyte control
- On-farm distribution and irrigation
  - Ditch lining or piping
  - Water-control structures
  - Land leveling or contouring
  - Sprinkler irrigation
  - Drip irrigation
  - Subsurface irrigation
  - Tailwater recovery
  - Irrigation scheduling
  - Improved tillage practices
  - Surface mulches
  - Pressure regulator

Irrigation System Evaluations
- Return-flow systems
- Field drainage
- Main drainage

Landscape Irrigation
- Efficient landscape design
- Low-water-use material
- Scheduled irrigation
- Efficient irrigation systems
- Tensiometers

Source: William O. Maddaus, *Water Conservation* (Denver, CO: American Water Works Association, 1987), 23.

Some water conservation measures, such as leak detection and repair, target water supply management by water suppliers. Such measures help water suppliers manage more efficiently and reduce losses from existing supplies.

TABLE 7-2

A TYPOLOGY OF SELECTED WATER CONSERVATION STRATEGIES

		Managing Agent	
		Water Supplier	Water User
Type of Action	Supply Management	Reducing water losses - supply audits - leak detection and repair - metering Pressure reduction Resource management - watershed management - reservoir evaporation suppression	[Not applicable]
	Demand Management	Pricing User restrictions Public education - information - user audits	Conservation practices Improved efficiency - appliances - fixtures Landscaping Reuse and recycling

Source: Authors' construct.

Supply conservation may reduce withdrawals, but it does not affect water demand. Suppliers also employ demand management techniques, such as public education, that have the potential to affect how much water is sold and used. Some demand management measures, such as user restrictions or plumbing code changes, may involve another actor such as a government agency. Users have no direct role in supply management, although every demand management technique implemented by users has an effect on supplies. However, water users play a prominent role in managing their own demand. They may, for example, change water-use practices or install water-efficient appliances and fixtures to conserve water.

The typology is imperfect to the extent that some water conservation measures seem to fall in more than one category. Metering, for example, is a supply management tool because it should help suppliers reduce the amount of unaccounted-for water. It also serves as a demand management tool because it sends a signal to water customers about their consumption and its cost. Similarly, the use of recycled water reduces the need for new water, and thus is a demand management tool. However, it also serves to conserve water supplies. Also, when reuse requires treatment, transportation, and distribution, water suppliers may be the managing agent.

This chapter reviews general categories of water conservation. A discussion of economic and regulatory issues, including rates and charges, is reserved for the following chapter.

Conservation of Supplies by Water Suppliers

According to a framework developed by the American Water Works Association (AWWA), water can be conserved by suppliers through reductions in water losses (supply audits, leak detection and repair, and metering), pressure reduction, and resource management (watershed management and evaporation suppression).[2]

Reducing Water Losses

Reducing water loss is a basic management responsibility for suppliers, and one that likely will receive increased attention in light of water conservation concerns. Water losses in public water systems, also referred to as unaccounted-for water, may be as high as 50 percent; 20 to 30 percent is considered a reasonable estimate for older systems, particularly in the northeastern part of the country.[3] Leakage is usually to blame for unaccounted-for water, but there are actually a number of other causes. When water is unmetered, it cannot be accounted for accurately. Thus, in one sense, unmetered water is identical to unaccounted-for water.

However, a further distinction can be made between legitimate losses and potentially recoverable losses. Legitimate losses include water main flushing, fire fighting, street washing, sewer flushing, and even recreation (open hydrants).[4] While a utility may have little control over losses due to legitimate reasons such as these, other types of water loss translate directly into a revenue loss. Potentially recoverable losses can be attributed to leakage, metering errors, major breaks, illegal connections, and miscellaneous inadvertent losses.

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[2] American Water Works Association, *Before the Well Runs Dry: Volume I--A Handbook for Designing a Local Conservation Plan* (Denver, CO: American Water Works Association, 1984).

[3] James W. Male, Richard R. Noss, and I. Christina Moore, *Identifying and Reducing Losses in Water Distribution Systems* (Park Ridge, NJ: Noyes Publications, 1985), 1.

A water supply audit, outlined in figure 7-1, is a framework for identifying and quantifying water losses. While it would be uneconomical

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Step 1: Quantify the Water Supply
1. Identify all water sources
2. Quantify water from each source
3. Verify and adjust source quantities

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Step 2: Quantify Authorized Metered Water Use
1. Identify metered uses
2. Quantify metered uses
3. Verify and adjust source quantities

↓

Step 3: Quantify Authorized Unmetered Uses
1. Identify authorized unmetered uses
2. Quantify authorized unmetered uses

↓

Step 4: Quantify Water Losses
1. Identify potential water losses
2. Estimate losses by type of loss

↓

Step 5: Analyze Water Audit Results
1. Estimate variable utility cuts
2. Estimate cost of leak detection survey
3. Compare benefits to cost
4. Conduct leak detection survey if justified

Fig. 7-1. Steps in a water supply audit as depicted by the California Department of Water Resources and reported in William O. Maddaus, *Water Conservation* (Denver, CO: American Water Works Association, 1987), 60.

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[4] Ibid.

and physically impossible for water suppliers to eliminate losses entirely, prudent management would dictate reducing losses as long as the benefits of doing so outweigh the costs. As water becomes more expensive (especially treated water) the incentive for reducing losses increases. Careful record keeping, metering, and an aggressive leak detection and repair program are essential ingredients to finding a solution.[5]

According to one study, leak detection and repair should be considered by supply managers even if it is costly and even if supplies are adequate.[6] In Arlington, Massachusetts, twenty-six leaks were repaired at a cost of $4,300. The savings amounted to more than 250 million gallons of water valued at $61,200. The savings gained by leak repair typically outweigh costs by a large amount, especially for older systems that have not been well maintained. In a severe water shortage, the cost of recovering even small losses may be well worth the expense of recovery. Meter accuracy also is essential to loss reduction. Twenty percent of meters between nine and nineteen years of age are inaccurate; 50 percent of those between nineteen and twenty-nine years of age are inaccurate.[7]

As noted above, metering is actually a tool for managing both supply and demand. Not only does it allow water suppliers to keep track of water supplies, improving the efficiency of their operations, it also informs users about their water consumption. Economic analysts have long hypothesized that customers with meters, as compared to those paying a flat rate for service, will use less water. One hypothetical model showed that metering reduced total water demand by 21 percent, lawn sprinkling by 32 percent, and return flow by 34 percent.[8] The research evidence, reported in table 7-3, supports the hypothesis to a large degree. Although some studies revealed no differences, some metered customers used as much as 45 percent less water than unmetered customers, although 25 percent is closer

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[5] Ibid., 5-6.

[6] American Water Works Association, *Before the Well Runs Dry*, 44.

[7] William D. Hudson, "Increasing Water Efficiency Through Control of Unaccounted-For Water," in American Water Works Association, *Water Conservation Strategies* (Denver, CO: American Water Works Association, 1980), 96.

[8] J. Ernest Flack, "Increasing Efficiency of Nonagricultural Water Use," in Ernest A. Engelbert and Ann Foley Scheuring, eds., *Water Scarcity: Impacts on Western Agriculture* (Berkeley, CA: University of California Press, 1984), 211.

TABLE 7-3

STUDIES OF WATER SAVINGS THROUGH METERING

Study Location	Approximate Study Duration	Sample Size	Water Savings in Percent
Small Cities			
Milan, Tennessee	1946-1948	Citywide	45%
Kingston, New York	1958-1963	Citywide	27
Zanesville, Ohio	1958-1961	Citywide	22
Large Cities			
Salt Lake City, Utah	1917-1950s	74% of service area	--(a)
Philadelphia, Pa.	1955-1960	27% of service area	28-45
Boulder, Colorado	1950s-1960s	Citywide	36
Calgary, Alberta	1968	14,755 metered and 61,575 flat rate	45
Central Valley cities, California	1970	Citywide	30
Denver, Colorado			
Johns Hopkins Study	1961-1966	Four flat-rate neighborhoods, study areas in other western cities.	--(b)
Green's Thesis	1972	Three of four flat-rate areas from Johns Hopkins projects plus surrounding metered areas.	13-30
Beck Report	1966-1968	Two flat-rate areas plus two metered areas from Aurora.	--(b)
Bryson's Thesis	1971	90,290 flat-rate residential services, 19,080 metered residences.	25
Brown and Caldwell	1980, 1981, and 1983	One group of 25 metered homes and two groups of flat-rate homes (42 total)	20

Source: Adapted from Brown and Caldwell, *Residential Water Conservation Projects*, *Summary Report* (Washington, DC: U.S. Department of Housing and Urban Development, 1984), 1-4 and 7-2.

(a) Universal metering was completed in 1929. Usage initially decreased but then increased by the early 1950s to levels comparable to 1917.

(b) Little difference noted between metered and flat-rate domestic (inside) use; however, sprinkling use was much less for metered residences.

to the norm. The effect of metering also may depend on the price differential between metered and unmetered service and demand elasticities.[9]

Brown and Caldwell, consultants to the U.S. Department of Housing and Urban Development, emphasize (as do preceding studies) that the principal effect of water metering is to reduce landscape irrigation, thus reducing warm-weather water usage. The study concludes that metered customers water their landscape more efficiently. Outdoor use, and lawn watering in particular, is probably the most discretionary area of use.

Pressure Reduction

Another hypothesis is that reducing water system pressure may conserve supplies by reducing losses through leakage as well as by reducing water use.[10] A pressure reduction from 100 pounds per square inch (psi) to 50 psi causes water flow at the tap to decrease by about one-third. Pressure reduction may be feasible where pressure is considered excessive (that is, greater than 80 psi).[11]

Pressure reduction valves for individual residences may cost about $50 but valves for water mains often cost several hundred dollars, not counting installation costs.[12] Studies of pressure reduction, summarized in table 7-4, indicate that potential savings may be limited. A study of Denver communities that is considered particularly reliable because of well-established patterns of water use and controls for climatic and demographic variables suggests that pressure reduction in the 30-40 psi range is associated with a 6 percent reduction in water use.[13]

For many water-using fixtures (such as toilets) and appliances (such as washing machines) use is based on volume, so a change in pressure will have

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[9] These issues are addressed in chapter 8.

[10] Brown and Caldwell, *Residential Water Conservation Projects, Summary Report* (Washington, DC: U.S. Department of Housing and Urban Development, 1984), 1-4 and 8-8.

[11] American Water Works Association, *Before the Well Runs Dry*.

[12] Ibid., 44.

[13] Brown and Caldwell, *Residential Water Conservation Projects*, 1-6.

TABLE 7-4

WATER SAVINGS THROUGH PRESSURE REDUCTION

Area	Pressure per Square Inch	Lot Size in Square Feet	Water Use in gcd (a)	Percent Savings (b)
Denver Communities (c)				
Southeast Englewood				
high pressure	70-90	10,700	191	
low pressure	42-48	9,800	180	6.1%
Happy Canyon Road				
high pressure	70-83	12,800	319	
low pressure	56-68	11,500	298	6.6%
Southeast Denver				
high pressure	97-105	10,500	222	
low pressure	64-85	11,000	228	-2.7%
Southwest Metro				
high pressure	87-107	7,800	151	
low pressure	60-67	9,400	136	9.9%
Watergate				
high pressure	90-110	10,350	198	
low pressure	35-55	10,250	180	9.1%
Comparative City Data				
Denver (d)				
high pressure	91	10,430	216	
low pressure	58	10,400	204	5.5%
Atlanta (e)				
high pressure	-- values ranged --		240	
low pressure			231	4.0%
Los Angeles (f)				
high pressure	-- values ranged --		208	
low pressure			202	3.0%

Source: Adapted from Brown and Caldwell, *Residential Water Conservation Projects, Summary Report* (Washington, DC: U.S. Department of Housing and Urban Development, 1984), 8-1 to 8-8.

(a) Gallons per capita daily. For the Denver study, outside water use was adjusted to account for differences in lot sizes.
(b) Relative to high-pressure group water use.
(c) Data for this study were collected between 1978 and 1980.
(d) Averages based on Denver community data (above).
(e) Based on data for 1981-1983, excluding 10 months in 1982 due to drought.
(f) Based on data for 1971-1982, excluding 1977-1979 due to drought. This study analyzed the effects of a pressure increase. Household use data were converted to per capita use data by assuming three persons per dwelling.

no effect. Nor will it affect the usage of people who do not use showers at the maximum capacity or those who take baths. Reducing water pressure may cause less wear on plumbing systems, fixtures, and appliances, but it is not expected to reduce indoor use significantly. Pressure reductions are likely to have more of an impact through reduced outdoor use (mainly irrigation) and reduced likelihood and magnitude of leaks.

Most water systems, as well as plumbing and irrigation systems, were designed to operate with a specified pressure level. Some uncertainty exists about operating at lower levels as low pressure may threaten water quality to a dangerous degree where water and wastewater lines are cross-connected. Increasing pressure after a low-pressure period may create a stress on pipes and loosen potential contaminants lining pipes. Pressure reduction also may violate state and local codes, threaten fire protection capabilities, and cause customer complaints. Any pressure reduction strategy also must consider topographical elevations, the reliability of pressure regulators, regulator maintenance, and replacement costs. Lower water pressures, and the accompanying water savings, are probably most feasible for new construction projects where all related design specifications can be made in concert.

Resource Management

Water resource management, if feasible, can also achieve water conservation goals. Watershed management can help prevent water supply contamination and regulate recharge flows to the water source. Watershed-management techniques that can be used to protect supplies against contamination or improve recharge flows include:[14]

- Evapotranspiration suppression (spraying watershed vegetation with a suppressant chemical to cover the plants' pores; used mostly in arid and semiarid regions).
- Forestry management (thinning forests in the watershed area to increase flows to the source; reduces water

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[14] American Water Works Association, *Before the Well Runs Dry*, 44.

consumption by trees, increases runoff, and generates income from lumber sales).

- Zoning (limiting or prohibiting inappropriate land uses in the watershed area; requires expertise in planning and law and must be enacted by local government).
- Purchase surrounding watershed land (maintaining land under direct control; may be expensive and difficult to acquire all of the land in the watershed).
- Subdivision regulations (requiring that development proceed in a way that does not harm the recharge area; requires expertise in planning and law and must be enacted by local government).

A final resource management strategy is evaporation suppression at the reservoir accomplished by covering open reservoirs.[15] The effectiveness of this strategy has not been demonstrated in humid regions where the rate of evaporation is less. As a general rule, evaporation suppression is not considered appropriate unless evaporation accounts for losses of 10 percent of water supplies in an arid or semiarid area.

Comparison of Supply Management Measures by Water Suppliers

The AWWA prepared a comparison of alternative supply management measures, as reported in table 7-5. The table compares metering, leak detection and repair, pressure reduction, watershed management, and evaporation suppression. Three broad types of impacts are analyzed: financial/economic, technical/environmental, and legal/institutional. The impacts themselves may be either positive or negative. All five types of supply management, for example, probably would require the water supplier to hire new personnel, but all five are likely to improve system efficiency as well. Such analysis is useful as a planning and evaluation tool for assessing supply management impacts.

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[15] Ibid.

TABLE 7-5

ANALYSIS OF SUPPLY MANAGEMENT PROGRAM IMPACTS

	Types of Programs				
Types of Impacts (+/-)*	Metering	Leak Detection and Repair	Pressure Reduction	Watershed Management	Evaporation Suppression
Financial/Economic					
Profits may increase (+)	X	X	X	-	-
Program costs may be high (-)	X	X	X	X	X
Expense may cause a temporary operating deficit (-)	X	X	X	-	-
Existing revenues may not cover program costs (-)	X	X	X	X	X
New water rate may be required to fund program (-)	X	X	X	-	X
Subsidy or grant from local, state, or federal government may be available (+)	X	X	-	-	-
New personnel may be needed (-)	X	X	X	X	X
Variable costs decrease, including energy (+)	X	X	X	X	-
Revenues may increase (+)	X	X	-	-	-
Technical/Environmental					
New source development may be postponed, scaled down, or eliminated (+)	X	X	X	X	X
System efficiency improves (+)	X	X	X	X	X
Energy consumption decreases (+)	X	X	X	-	-
Legal/Institutional					
Utility may be unable to accept/obtain grant for program (-)	X	X	-	-	-
Lack of cooperation from local government may complicate implementation (-)	X	X	X	X	X
Community opposition (-)	-	-	X	X	-

Source: Adapted from American Water Works Association, *Before the Well Runs Dry: Volume I--A Handbook for Designing a Local Conservation Plan* (Denver, CO: American Water Works Association, 1984), 26.

* The designation of impacts as positive or negative (+/-) has been added by the authors and is based on generalized assumptions about the water supplier's perspective.

Demand Management by Water Suppliers

A framework developed by the AWWA recognizes three general areas of demand management by water suppliers: pricing, user restrictions, and public education.[16]

Pricing

Because higher prices send a signal to consumers to use less of a good, pricing can be used as a conservation tool. Because pricing can help water suppliers maintain their revenues (even as consumption drops), some believe it should be considered as a part of most water conservation programs.[17] Pricing has been shown to be most effective in reducing peak use by residential customers and average use by commercial and industrial customers.

How much conservation can be induced by pricing depends primarily on elasticities of demand for water, which in turn may depend on a variety of factors. The higher the price, the higher the expected water savings. A sharp rate hike is expected to induce conservation almost immediately, although there may be a tendency for customers to become accustomed to the new prices and over time gradually increase their consumption. Conservation also may occur "naturally" as prices gradually edge upward and consumers install more efficient water fixtures and change their consumption habits over time.[18]

The use of pricing as a conservation tool requires metering, a rate survey or cost-of-service study, and approval by regulatory or municipal authorities. One study outlines six steps for designing a new water rate for conservation purposes:[19]

- Express the percentage reduction goal numerically.

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[16] Adapted from American Water Works Association, *Before the Well Runs Dry*. The term "user restrictions" is used here instead of "regulation."

[17] Ibid., 45.

[18] Darryll Olsen and Allan L. Highstreet, "Socioeconomic Factors Affecting Water Conservation in Southern Texas," *American Water Works Association Journal* 79, no. 3 (March 1987): 68.

[19] American Water Works Association, *Before the Well Runs Dry*, 57-58.

- Estimate how much water use will drop after the price goes up (the elasticity value).

- Determine the percentage change in price needed to achieve the demand reduction goal.

- Determine what the new revenues will be as a result of the new price level.

- Compare the new revenues with costs, keeping in mind that variable costs will drop as water use drops.

- Pick a rate structure.

Naturally, opposition by customers and governmental authorities can be a barrier to price increases. In the abstract, however, public support for using metering and higher rates to induce conservation appears to be fairly high.[20] The issue of pricing in the regulatory context is explored in the following chapter.

User Restrictions

While pricing manipulates demand indirectly, the effect of user restrictions is more direct. Some target reductions in average demand; others target reductions in peak demand. Some are used for short-term conservation goals; others are used for long-term conservation goals. For some measures, the typical percentage reduction in demand is small; in others, it is large. User restrictions also may require a program of monitoring, enforcement, and penalties in order to assure compliance. These efforts may be costly.

Five main types of user restrictions (or regulations) may be imposed by water suppliers as part of a demand management strategy. They are:[21]

- To restrict a specific water use;

- To restrict the time during which specific uses are allowed;

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[20] J. Ernest Flack and Joanne Greenberg, "Public Attitudes Toward Water Conservation," in *American Water Works Journal* 79, no. 3 (March 1987); and Olsen and Highstreet, "Socioeconomic Factors."

[21] American Water Works Association, *Before the Well Runs Dry*, 63.

- To allow specific uses (such as pool filling) by permit only;
- To restrict the quantity of water that can be used; and
- To require installation of low-water-using appliances only.

The typical measures for reducing average demand include: rationing, imposing moratoriums on new hook-ups, requiring restaurants to serve water only on request, plumbing code changes, and retrofitting appliances.[22] Peak demand reductions typically are accomplished by banning uses such as car washing and irrigation; limiting car washing and irrigation by months, days, or hours of the day; requiring landscape irrigation with hand-held hoses only; and requiring permits for pool filling. Rationing and use restrictions are noteworthy because they probably will not be well accepted on a long-term basis. As suggested in the previous chapter, they may be more suited for demand management during a drought.

Public Education

The key to the public's acceptance of user restrictions and most other conservation measures is public education. Public education programs by water suppliers assume that an informed public is more capable of helping achieve water conservation goals. Public education and voluntary cooperation may be the only conservation strategy a water supplier uses. It is probably more typical that an educational program is used in conjunction with other conservation measures. A change in price or a user restriction, for example, may require a media campaign to spread the word about the water supplier's conservation goals and enlist the public's support. Whatever the policy, it is likely to be more palatable if consumers are informed and their cooperation is enlisted by the water supplier. Furthermore, many of the demand management measures that users employ can be stimulated by the public education efforts of water suppliers. In this sense, public education also has relevance for the effectiveness of all types of water conservation measures.

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[22] Ibid.

A variety of public education techniques are available to water suppliers.[23] Their appropriateness may depend on the local community culture. Some are more appropriate for small, close-knit communities, while others are suited to large urban areas. Some inexpensive measures include local newspaper articles, posters and public displays, fairs, contests, flyers, distribution of reminder items, school programs, bill inserts, pamphlets and handbooks, and newsletters. More expensive measures include local newspaper advertisements, information centers, speaker's bureaus, billboards, television and radio advertisements, films and slide shows, water-saving-fixture test programs, and direct customer assistance.

One of the more expensive methods in an information program is to provide water users with a way to analyze their water consumption, typically accomplished through a water audit. Like an energy audit, the water audit can identify areas where water use may be excessive or wasteful because of user habits, faulty fixtures or appliances, or leaks. A simple water audit can be conducted by residential users through the use of a kit. Kits may include information on how to conserve water as well as conserva-tion devices, such as flow restrictors. A more advanced and detailed water audit may be especially useful for industrial and commercial users whose demand is high and whose potential for conservation is especially great.

Comparison of Demand Management Measures by Water Suppliers

The AWWA's comparison of demand management measures--pricing, user restrictions, and public education--from the standpoint of impacts on investor-owned water utilities is provided in table 7-6. The table compares impacts organized into financial/economic, technical/environmental, social/political, and legal/institutional categories. As indicated, each demand management measure has advantage and disadvantages. More negative impacts are associated with the financial/economic category and more positive impacts are associated with the technical/environmental category. As with supply management measures, this type of analysis is especially useful in planning and evaluating water conservation programs.

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[23] American Water Works Association, *Before the Well Runs Dry*, 67.

TABLE 7-6

ANALYSIS OF DEMAND MANAGEMENT PROGRAM IMPACTS FOR INVESTOR-OWNED WATER UTILITIES

	Types of Programs		
Types of Impacts (+/-) (a)	Pricing	Restrictions(b)	Public Education
Financial/Economic			
Variable costs (energy, chemicals) decreased within utility (+)	X	X	X
Decrease in user's energy and/or sewer bills (-)	X	X	X
Investment for new source postponed, reduced, or eliminated (+)	X	X	X
Fire protection, public health and lifestyle maintained, when shortage is avoided (+)	X	X	X
Users' expenditure to buy water saving fixtures or reuse/recycle systems (-)	X	X	X
Revenues usually increase (+)	X	-	-
User's water bills increase (-)	X	-	-
Revenue increase results in system reinvestment, improved customer service (+)	X	-	-
Large volume users may develop own source with subsequent loss of their revenues to utility (-)	X	X	-
Increased price or restriction to large volume users may result in production cutbacks, employee layoff, increases in product prices (-)	X	X	-
Utility expenditure to do rate study (-)	X	-	-
User's bill decreases, at least temporarily (+)	-	X	X
Revenue loss necessitating rate hike (-)	X	X	X
Revenue loss may result in cutback in utility's operation and/or maintenance (-)	X	X	X
Utility expenditures to pay for enforcement (-)	-	X	-
New industry may not be attracted to community (-)	X	X	-
Utility expenditure for education materials (-)	-	-	X
Regulatory board limits rate of return and flexibility in rate setting (-)	X	-	-
9- to 12-month-approval process by regulatory board may complicate conservation program and supply problem (-)	X	-	-
If there is a revenue loss, a rate hike may not be permitted by regulatory board (-)	X	X	X
Technical/Environmental			
New source development postponed, reduced, or eliminated (+)	X	X	X
Additional connections possible (+)	X	X	X
Reduced operation and maintenance at utility (+)	X	X	X
Reduced waste water volume (+)	X	X	X

TABLE 7-6--Continued

Types of Impacts (+/-) (a)	Types of Programs Pricing	 Restric-tions(b)	 Public Education
Technical/Environmental (continued)			
Reduced operation and maintenance at sewage treatment plant or septic tank system (+)	X	X	X
Increased capacity and life of sewage treatment plant or septic tank system (+)	X	X	X
Reduced energy consumption (+)	X	X	X
Maintain water supply source level and/or flow (+)	X	X	X
Stream flows may vary (higher if less water is extracted; lower if less wastewater is discharged) (+/-)	X	X	X
Waste water pollutant concentration increases (-)	X	X	X
In marginally low-grade sewers, waste water transportation efficiency may decrease (-)	X	X	X
Damage to lawns and gardens if outdoor watering is not possible (-)	X	X	X
Industrial or large-volume users may develop own source or relocate (-)	X	X	-
System improvement because of reinvestment (revenue increase) (+)	X	-	-
System degradation of operation and maintenance reduced (revenue loss) (-)	-	X	X
Social/Political			
Community lifestyle maintained (+)	X	X	X
Community water related recreation may be jeopardized (-)	X	X	X
Peer pressure to comply with program (+)	-	X	X
Regulatory board opposition to program (-)	X	-	-
User and special interest group opposition (-)	X	X	-
Political opposition to program (-)	X	X	-
Fairness of plan must be carefully considered (potentially -)	X	X	-
Program may affect politics of community growth and development (-)	X	X	-
User and political cooperation with program and understanding of utility operations increased (+)	-	-	X
Cooperation with enforcement authority to implement program may be difficult (-)	-	X	-
Cooperation with school department and other community departments to incorporate program may be difficult (-)	-	-	X
Well received by users and local government (+)	-	-	X

TABLE 7-6--Continued

Types of Impacts (+/-) (a)	Types of Programs Pricing	 Restrictions(b)	 Public Education
Legal/Institutional			
Bond and debt obligations must be maintained (-)	X	X	X
Regulatory board may determine where excess revenues can be spent (-)	X	-	-
Local, state, and federal laws may limit options to users on how to conserve, particularly health and safety regulations (-)	X	X	X
Contradictions between surface and groundwater laws may inhibit comprehensive supply management (-)	X	X	X
Cooperation among community departments may improve or complicate implementation (+/-)	X	X	X
Cooperation with enforcement agency may improve or complicate implementation (+/-)	-	X	-
Local, state, regulatory board, and federal laws may limit use of some programs (-)	X	X	-
Coordination with school departments and media may be necessary (-)	-	-	X
May improve coordination of government bodies involved with program (+)	-	-	X
If water supply and waste water operations are independent, coordination of program with each other may be difficult (-)	X	X	X
Regulatory board may not allow pricing for conservation (-)	X	-	-

Source: Adapted from American Water Works Association, *Before the Well Runs Dry: Volume I--A Handbook for Designing a Local Conservation Plan* (Denver, CO: American Water Works Association, 1984), 38-41.

(a) The designation of impacts as positive or negative (+/-) has been added by authors and is based on generalized assumptions about the water supplier's perspective.

(b) Referred to as regulation (of water use) in the original.

Demand Management by Water Users

Water users can manage their demand by changing water-use practices, installing more efficient appliances and fixtures, using water-saving landscaping, and recycling the water they use. Some users may be motivated by ecological reasons and conserve for the sake of conservation. Others may conserve for economic reasons, perhaps in response to a price increase. Some may respond to user restrictions and high penalties for noncompliance. Others may be motivated by a water supplier's plea for conservation during a period of water shortage. Regardless of motivations, all demand management strategies ultimately depend on users to reduce their water consumption.

Conservation Practices

The premise behind the adoption of conservation practices is that turning on the tap does not have to be a "mindless act." Changes in ways of doing things can reduce water consumption greatly, often without adverse effects on lifestyle. Conservation practices can be identified for all types of water uses.[24] In the industrial sector, for example, some manufacturing processes may be altered to reduce or even eliminate water use. Technological advances also may reduce water needs in electricity generation.[25] Numerous soil and water conservation methods are applied in the agricultural sector for irrigation and other farm operations. Large water users in all of these sectors already are aware of many conservation practices and the economic advantages of implementing them.

Many residential water users, however, may lack the information needed to evaluate their water consumption habits and institute conservation behavior. Economic incentives for conserving water also may be more limited. Table 7-7 reports typical personal water consumption habits and the savings that can be achieved through conservation. The morning shave with the tap

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[24] Brent Blackwelder and Peter Carlson, *Survey of the Water Conservation Programs in the Fifty States: Model Water Conservation Program for the Nation* (Washington, DC: Bureau of Reclamation, U.S. Department of the Interior, 1982).

[25] Electric Power Research Institute, "Water Water Everywhere But...," *EPRI Journal* 4, no. 8 (October 1979): 6-13.

TABLE 7-7

PERSONAL WATER CONSERVATION

Activity	Normal Use and Quantity Used	Conservation Use and Quantity Used
Toothbrushing	Tap running 10 gallons	Wet brush, rinse briefly 0.5 gallons
Shaving	Tap running 20 gallons	Fill basin 1 gallon
Tub bath	Full bath 36 gallons	Minimum water level 10-12 gallons
Shower	Water running 25 gallons	Wet down, soap up, rinse 4 gallons
Dishwashing	Tap running 30 gallons	Wash and rinse in sink or pan 5 gallons
Automatic dishwasher	Full cycle 16 gallons	Short cycle 7 gallons

Source: American Water Works Association as reported in Brent Blackwelder and Peter Carlson, *Survey of the Water Conservation Programs in the Fifty States: Model Water Conservation Program for the Nation* (Washington, DC: Bureau of Reclamation, U.S. Department of the Interior, 1982), 9.

running, for example, uses twenty gallons of water while filling the basin uses one gallon. Outdoor water use habits also may be a target for conservation efforts. An example is using a broom instead of water to clean outdoor areas. Another is watering landscape during periods of the day when evaporation is less and, of course, avoiding the tendency to overwater.

Changes in personal habits may not be a reliable method for saving large quantities of water, although in a genuine crisis all savings count. Personal water use also is not a suitable target for user restrictions. Certain habit changes, particularly those that reduce waste, are consistent with the wise-use-of-water theme and may in turn carry over to other sectors where water use is greater and conservation may be more essential. Thus, providing information to the public about conservation practices may be an appropriate element of a water conservation program.

Efficient Fixtures and Appliances

One of the most promising areas of demand management is the installation of more efficient water-using fixtures and appliances. This fact has stimulated interest in modifying plumbing codes to require more efficient fixtures and appliances in new construction and replacements.[26] As more information becomes available to consumers, water efficiency may become a purchase criterion for water-using appliances much as energy efficiency has become a purchase criterion for electrical appliances.

Table 7-8 compares water use by conventional household fixtures and appliances with more efficient models. The potential savings are significant, even when replacing conventional fixtures with merely low-flow devices. Some technologies, however, have the potential for larger water savings. Air-assisted toilets and showerheads, for example, can achieve water savings of nearly 90 percent. While the potential savings from water-efficient appliances, such as clothes washers, are not as dramatic they still may be significant.

In 1984, the U.S. Department of Housing and Urban Development (HUD) published a comprehensive set of findings on the actual performance of water-conserving fixtures and appliances.[27] Nonconserving, intermediate, and conserving devices are compared in table 7-9. Based on a demonstration study of approximately two hundred households (in which consumers did not change their general water-use habits), more efficient fixtures and appliances were associated with about 23 percent less per capita water use (from 77.3 to 59.7 gallons). Relative amounts of water use (shown in percentages) were largely unaffected.

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[26] On plumbing codes see chapter 9.

[27] Brown and Caldwell, *Residential Water Conservation Projects*.

TABLE 7-8

POTENTIAL WATER SAVINGS FROM EFFICIENT HOUSEHOLD FIXTURES AND APPLIANCES

Fixture/Appliance	Water Use (metric)	Water Savings Over Conventional Fixtures (percent)
Toilets	*Liters/use*	*Percent saved*
Conventional	19	--
Common low-flush	13	32
Washdown	4	79
Air-assisted	2	89
Clothes Washers	*Liters/use*	*Percent saved*
Conventional	140	--
Water recycle	100	29
Front-loading	80	43
Showerheads	*Liters/minute*	*Percent saved*
Conventional	19	--
Common low-flow	11	42
Flow-limiting	7	63
Air-assisted	2	89
Faucets	*Liters/minute*	*Percent saved*
Conventional	12	--
Common low-flow	10	17
Flow-limiting	6	50

Source: Sandra Postel, "Increasing Water Efficiency," in Lester R. Brown, et al., *State of the World 1986* (New York: W. W. Norton and Co., 1986), 55.

Table 7-10 compares the HUD demonstration project findings with estimates of expected water savings found in other literature. The authors conclude that even though the water savings were not as great as expected, the savings of individual fixtures taken together are significant. Furthermore, the findings greatly improve the confidence with which actual

TABLE 7-9

WATER CONSERVATION SAVINGS IN THE HUD DEMONSTRATION PROJECT

Appliance/ Fixture	Conservation Measure	Daily Fixture Use per Capita	Water Consumption per Use	Daily per Capita Use in Gallons	(%)
Group I: Nonconserving					
Toilets	-----	4.0 flushes	5.5 gal./flush	22.0	28%
Wash. machine	-----	0.3 loads	55.0 gal./load	16.5	22
Showers	-----	4.8 minutes	3.4 gal./minute	16.3	21
Faucets	-----	(estimated)	(estimated)	9.0	12
Baths	-----	.14 baths	50.0 gal./bath	7.0	9
Toilet leaks	-----	(estimated)	(estimated)	4.1	5
Dishwasher	-----	0.17 loads	14.0 gal./load	2.4	3
Total				77.3	100%
Group II: Intermediate					
Toilets	displacements	4.0 flushes	4.8 gal./flush	19.2	28%
Wash. machine	low-use appliance	0.3 loads	47.5 gal./load	14.3	22
Showers	flow restrictors	4.8 minutes	3.4 gal./minute	12.6	18
Faucets	-----	(estimated)	(estimated)	9.0	13
Baths	-----	0.14 baths	50.0 gal./bath	7.0	10
Toilet leaks	-----	(estimated)	(estimated)	4.6	7
Dishwasher	low-use appliance	0.17 loads	14.0 gal./load	1.7	2
Total				68.4	100%
Group III: Conserving					
Toilets	low-flush	4.0 flushes	3.5 gal./flush	14.0	23%
Wash. machine	low-use appliance	0.3 loads	42.0 gal./load	12.6	22
Showers	low-flow	4.3 minutes	1.9 gal./minute	8.2	14
Faucets	aerators	(estimated)	(estimated)	8.5	14
Baths	-----	0.14 bath	50.0 gal./bath	7.0	12
Toilet leaks	-----	(estimated)	(estimated)	8.0	13
Dishwasher	low-use appliance	0.17 load	8.5 gal./load	1.4	2
Total				59.7	100%

Source: Adapted from Brown and Caldwell, *Residential Water Conservation Projects, Summary Report* (Washington, DC: U.S. Department of Housing and Urban Development, 1984), 4-8 to 4-9. The data are based on a demonstration study of approximately 200 households.

TABLE 7-10

WATER CONSERVATION SAVINGS IN THE HUD DEMONSTRATION PROJECT COMPARED WITH PREVIOUS ESTIMATES

Water Conservation Practice	Previous Literature Estimate	HUD-Observed Water Savings (a)
	In Gallons Per Capita Daily (b)	
Revised plumbing code (3-gpm showerheads, 3.5-gal./flush toilets, water efficient dishwashers)	20.0	16.3
3.0 gallons per minute shower head	8.5	7.2
0.5 gallons per minute shower head	16.3	13.8
3.5 gallons/flush toilet	12.5	8.0
0.5 gallons/flush toilet	24.3	19.6
Water-efficient dishwasher	na	1.0
Water-efficient clothes washer	na	1.7
Retrofit kit	13.5	5.5
Fix toilet leaks	na	24 gallons/day/toilet
Water meters	35 percent	20 percent
New homes with 30-40 psi lower pressure	10 percent	3 to 6 percent

Source: Adapted from Brown and Caldwell, *Residential Water Conservation Projects, Summary Report* (Washington, DC: U.S. Department of Housing and Urban Development, 1984), 1-7.

(a) The U.S. Department of Housing and Urban Development (HUD) data are based on a series of large-scale demonstration studies. Savings are based on a comparison with conventional fixtures and appliances. The estimate for savings from metering applies to cities with a climate comparable to that for Denver, Colorado.

(b) Unless otherwise noted.

savings can be predicted, and make it possible to conduct an accurate evaluation of the cost-effectiveness of many water conservation strategies.

Probably the greatest potential for indoor water conservation is through the adoption of plumbing codes that require low-flush toilets and low-flow showerheads. Recent studies show that low-flush toilets not only reduce demand for water and sewer services and lower the costs of these services to the consumer, but their performance equals or exceeds that of conventional toilets.[28] Amy Vickers estimates that retrofitting toilets to the 1.5-gallon-per-flush variety in Boston will save between $39 (replacing a 3.5-gallon fixture) to $108 (replacing a 7.0-gallon fixture) in 1989 water and sewer charges per household. The corresponding water savings associated with retrofitting will amount to between 11,680 and 32,120 gallons annually per household. Comparable savings can be gained by installing low-flow shower-heads. The most advanced water-efficient fixtures, however, are still costly, particularly for use in retrofitting. Also, an area requiring further analysis is the effect of more efficient fixtures on sewer flows.

Water-Saving Landscaping

As noted in chapter 3, about one-third of typical residential water use is for outdoor purposes, mostly landscape watering. Outdoor use is more discretionary and generally more price elastic. User restrictions during periods of water shortage often target outdoor use. One way to reduce outdoor water consumption is through water-efficient landscaping.

In some areas, landscaping choices have not reflected the realities of limited water supplies. Frank Welsh contrasts the landscaping cultures of two Arizona cities:

> A drive through the desert cities of Phoenix and Tucson provides a visual reflection of prevailing water-use habits. In Tucson, one is never quite sure where the desert ends and the city begins. Drought resistant vegetation is the landscape theme. Driving through Phoenix is like driving through "Any City, U.S.A." when it comes to the landscaping. People seem to have brought their lawns with them when they left the northern climes. Lakes, fountains, and swimming pools are common.[29]

Proponents of "xeriscape," or landscaping for dry conditions, point out the dramatic differences in water requirements of different types of grasses. Although bluegrass is a popular species, it is also a high water-consumption species. The answer is not a gravel yard, but a well-planned landscape of low water-consuming plant species.[30] Bluegrass, for example, requires 18 gallons per square foot per year, while tall fescue requires 12 gallons and wheat grasses require 7 gallons. Some low-water requiring trees, shrubs, and groundcover require only 1 gallon of water per square foot each year. In addition to plants themselves, some studies emphasize ways to improve irrigation efficiency through technologies such as more accurate and reliable measurement of soil conditions.[31]

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[28] Amy Vickers, "New Massachusetts Toilet Standard Sets Water Conservation Precedent," *American Water Works Association Journal* 81, no. 3 (March 1989), 48-51.

[29] Frank Welsh, *How to Create a Water Crisis* (Boulder, CO: Johnson Books, 1985), 59.

A substantial literature has emerged to facilitate landscape planning, design, and management that incorporates dryness and drought considerations. Many, for example, recommend planting drought-resistant species of grasses, shrubs, and trees as well as using better water management practices. One comprehensive reference source addresses the following strategies:[32]

- Controlling the amount of water falling on the site
- Using drought resistant vegetation
- Leaving plants in a stress condition
- Erecting wind barriers
- Redesigning or renovating to reduce water requirements
- Altering cultivation practices
- Modifying soils
- Expanding the use of mulch
- Reusing water
- Making water "wetter"
- Establishing water priorities
- Altering or adjusting irrigation practices
- Using irrigation water more efficiently

Water shortages in arid and semiarid regions have heightened awareness and interest in the water-use aspects of land-use planning and landscape design. One study identified twenty-five cities in Arizona, California, Colorado, and Texas that have instituted xeriscape water conservation programs using their own personnel and local budgets.[33] In more than half of these cities, the program is implemented by the municipal water utility. Several have enacted or proposed regulations or ordinances promoting xeriscape. In the past, planners and developers probably could assume that water would be available in necessary quantities for whatever purposes they envisioned.[34] Today, the recognition that water will not always be readily available may pose a significant constraint.

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[30] The Front Range Xeriscape Task Force, *Xeriscape: Water Conservation Through Creative Landscaping* (Denver, CO: Metro Water Conservation, Inc., 1987), 27.
[31] Gail Richardson and Peter Mueller-Beilschmidt, *Winning with Water: Soil-Moisture Monitoring for Efficient Irrigation* (New York: Inform, Inc., 1988).
[32] Gary O. Robinette, *Water Conservation in Landscape Design and Management* (New York: Van Nostrand Reinhold Company, 1984).

Water Recycling and Reuse

Water recycling and reuse also are demand reduction strategies for dealing with water scarcity. For some applications, depending on technical feasibility, recycling and reuse may be the prerogative of the water user and conducted on the user's premises. This is the case in the recycling of cooling water used in various manufacturing processes. Water reuse on a large scale, particularly wastewater reuse, typically requires special handling and treatment by water suppliers. Regardless of the managing agent, recycling and reuse reduce demand for freshwater withdrawals.

Garret P. Westerhoff and Judy Berkun identified five significant trends in the water reuse field.[35] First is the growing need to conserve water for potable uses. Second is changing concerns about health effects. Third is that drinking water costs will rise significantly. Fourth is that water reuse will gradually gain public and regulatory acceptance. Fifth, upgraded treatment technologies will enter the reuse field. As the barriers to water reuse are overcome, treated wastewater possibly will become a supply alternative that can be "evaluated against other sources solely on an economic basis."[36] Increased acceptance includes a realization that, "drinking water cannot be *purely* two parts of hydrogen and one of oxygen, risk-free."[37] According to some analysts, wastewater has the potential to be as economical and reliable (and of equal quality) as water from other sources.

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[33] The Front Range Xeriscape Task Force, *Xeriscape*, 27. For more on local xeriscape programs see chapter 9.

[34] Welford Sanders and Charles Thurow, *Water Conservation in Residential Development: Land-Use Techniques* (Chicago: American Planning Association, 1982).

[35] Garret P. Westerhoff and Judy Berkun, "Water Reuse 2000: Trends Influencing Change," *Water Research Quarterly* 6, no. 1 (October-December, 1987): 10-14.

[36] Ibid., 14.

Table 7-11 describes possibilities for residential reuse based on original use and treatment requirements. In general, reuse potential is far

TABLE 7-11

POTENTIAL FOR RESIDENTIAL WATER REUSE

	Corresponding Reuse*										
Original Use	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
(1) Toilet	2	-	-	-	-	-	-	-	-	-	-
(2) Irrigation (a)	1	1	1	-	1	-	-	-	-	-	-
(3) Sprinkler (b)	1	1	1	-	1	-	-	-	-	-	-
(4) Kit. sink/grinder	1	1	1	-	-	-	-	-	-	-	-
(5) Carwash (c)	1	0	1	-	1	-	-	-	-	-	-
(6) Laundry (d)	1	0	1	-	1	1	-	-	-	-	-
(7) Pool	1	3	3	-	1	1	2	-	-	-	-
(8) Shower/tub	1	0	1	-	1	1	-	1	-	-	-
(9) Bathroom sink	1	-	1	-	1	-	-	-	-	-	-
(10) Dishwasher	1	0(e)	1(e)	1	1	-	-	-	-	1	-
(11) Cooking	1	0	1	0	1	-	-	-	-	0	0

Source: M. Milne (1976) as reported in J. Ernest Flack, "Increasing Efficiency of Nonagricultural Water Use," in Ernest A. Engelbert and Ann Foley Scheuring, eds., *Water Scarcity: Impacts on Western Agriculture* (Berkeley, CA: University of California Press, 1984), 137.

* Key:
0 Reusable directly with treatment
1 Reusable with settling and/or filtering (primary treatment)
2 Reusable with settling, filtering, and chemical treatment, usually chlorination (secondary treatment)
3 If not chlorinated
- Not reusable or impractical

(a) Difficult to collect; large orifice (unpressurized open hose or channel).
(b) Difficult to collect; small orifice (pressurized).
(c) Difficult to collect.
(d) Assumes no fecal matter.
(e) Special soaps required.

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[37] Ibid. Emphasis added.

greater for so-called gray water, which contains soap and detergents, as compared with what is referred to as black water, which is contaminated with organic matter. Of course, the implementation of reuse on the premises for most residences today still would be cost-prohibitive. The barriers to water reuse for domestic supply on a larger scale--including cost, technical feasibility, stringent drinking water standards, and cultural norms--remain formidable. Perhaps most promising in terms overcoming these barriers is the reuse of gray water for outdoor use, namely urban irrigation.

By comparison, water recycling in manufacturing already is well established, as indicated in table 7-12. Between 1954 and 1978, United States manufacturers doubled the number of times they used each cubic meter of water. In the petroleum and coal products area, recycling is particularly promising. The cost of water may play an important role in determining future recycling rates.

TABLE 7-12

WATER RECYCLING RATES IN UNITED STATES MANUFACTURING INDUSTRIES

Year	Paper and Allied Products	Chemicals and Allied Products	Petroleum and Coal Products	Primary Metal Industries	All Manufacturing
	Number of Times Each Cubic Meter is Used				
1954	2.4	1.6	3.3	1.3	1.8
1959	3.1	1.6	4.4	1.5	2.2
1964	2.7	2.0	4.4	1.5	2.1
1968	2.9	2.1	5.1	1.6	2.3
1973	3.4	2.7	6.4	1.8	2.9
1978	5.3	2.9	7.0	1.9	3.4
1985*	6.6	13.2	18.3	6.0	8.6
2000*	11.8	28.0	32.7	12.3	17.1

Source: Sandra Postel, "Increasing Water Efficiency," in Lester R. Brown, et al., *State of the World 1986* (New York: W. W. Norton and Co., 1986), 49.

* Data for 1985 and 2000 are projected.

Table 7-13 reports the issues involved in water reuse for irrigation, although many of the issues apply to all forms of reuse. According to the federal Office of Technology Assessment, crops irrigated with wastewater

TABLE 7-13

WATER REUSE ISSUES IN IRRIGATION

Resource Issues

- Effluent quality
  - Nutrient content
  - Heavy metal content
  - Pathogen content
- Soil productivity
  - Salt buildup
  - Toxicity buildup
  - Viral contamination
  - Physical degradation
- Crop production
  - Fertilizer and water requirements
  - Crop growth and yields
  - Crop uptake of nutrients
  - Crop uptake of toxics and pathogens
- Animal health
  - Animal uptake of nutrients
  - Animal transmission of pathogens to human consumers
- Groundwater quality
  - Path of water to water table
  - Quality of water reaching ground water
- Air quality (sprinkler irrigation)
  - Health effects for workers and nearby residents
  - Odor considerations

Social and Economic Issues

- Human health effects
  - Contact with effluent by farmworkers
  - Contact with plant and animal products by consumers

Social and Economic Issues (cont.)

- Social factors
  - Public attitudes toward application
  - Public attitudes by consumers of products
- Economic considerations
  - Water pricing
  - Transportation costs
  - Subsidies for those who use water
  - Facilities for water storage
  - Value in alternate uses
  - Type of material contained in water

Institutional Issues

- Water treatment facilities
  - Adequacy and reliability of treatment prior to application
  - Adequacy of storage facilities during periods of nonapplication
- Monitoring
  - Need for monitoring air, effluent, groundwater, crop, and soil quality
- Legal issues
  - Ownership and sale of water
  - Water rights
  - Liability for damages
  - Responsibility for monitoring
  - Guidelines for water reuse (e.g., crops to be grown, amount of water to be applied)
  - Effect on downstream users (third parties), if water previously was part of return flows

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Source: William H. Bruvold (1982) as reported in Office of Technology Assessment, "Waste Water Reuse," in David H. Speidel, Lon C. Ruedisili, and Allen F. Agnew, eds., *Perspectives on Water: Uses and Abuses* (New York: University of Oxford Press, 1988), 167.

yield the same or more as conventionally irrigated crops.[38] However, because crops vary in their tolerance to wastewater, the amount of dilution may need to be varied. Wastewater also has the potential to reduce reliance on added fertilizer, but many questions about long-term impacts on soil and water quality and public health remain. The cost and potential hazards of handling wastewater must be weighed against the economic advantages of reuse. Thus, the widespread application of reuse technology will require considerable planning and monitoring.

Conservation Programs by Water Suppliers

Conservation planning and conservation programs often combine supply and demand management measures. A framework for designing a conservation program based on those conservation options available to water suppliers is depicted in figure 7-2.[39] At the outset, the model emphasizes assessing the potential savings presented by supply management measures (such as metering, leak detection and repair, pressure reduction, watershed management, and evaporation suppression). Only when these options have a low potential does the framework suggest considering demand management options (such as pricing, user restrictions, and public education).

Regardless of which path is chosen--supply management or demand management--the following steps are parallel. First is the evaluation of cost-effectiveness and impacts. Second is the identification of actions to minimize adverse impacts. Third is the choice of a management program. Fourth is the evaluation and selection of specific hardware and software for implementation of the program. Finally, the framework calls for a summary of the plan's computer hardware and software requirements.

Because it relies on many factors beyond the control of the water supplier, demand management may require an additional evaluation process. According to one study, seven areas should be evaluated when considering alternative demand management programs:[40]

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[38] Office of Technology Assessment, "Waste Water Reuse," in David H. Speidel, Lon C. Ruedisili, and Allen F. Agnew, eds., *Perspectives on Water: Uses and Abuses* (New York: University of Oxford Press, 1988), 167.

[39] American Water Works Association, *Before the Well Runs Dry*, 67.

[40] Maddaus, *Water Conservation*, 24.

Identify Problem and Establish Goal

↓

High Potential <---------- *Assess Potential of Supply Management* ----------> Low Potential

↓

Cost-Effectiveness and Impact Analyses of Five Supply Management Programs
- Metering
- Leak detection and repair
- Pressure reduction
- Watershed management
- Evaporation suppression

↓

Identify Actions to Minimize Adverse Impacts
- Obtain extra funds
- Gain public support and cooperation
- Consider using supplemental supply or demand programs to meet goal

↓

Choose Supply Management Program(s)
- Metering
- Leak detection and repair
- Pressure reduction
- Watershed management
- Evaporation suppression

↓

Evaluate/Select Specific Hardware and Software

↓

Cost-Effectiveness and Impact Analyses of Three Demand Management Programs
- Pricing
- User restrictions
- Public education

↓

Identify Actions to Minimize Adverse Impacts
- Obtain extra funds
- Gain public support and and cooperation
- Consider using supplemental supply or demand programs to meet goal

↓

Choose Demand Management Program(s)
- Pricing: design a new water rate
- Restrictions: draw up water use Restrictions
- Education: develop education campaign materials

↓

Evaluate/Select Specific Hardware and Software
- Water saving fixtures
- Reuse/recycle systems
- User habit changes

Summarize Conservation Plan

Supply Management Program(s)
- Hardware
- Software

Demand Management Program(s)
- Hardware
- Software

Fig. 7-2. Steps in designing a water conservation program as adapted from American Water Works Association, *Before the Well Runs Dry: Volume I--A Handbook for Designing a Local Conservation Plan* (Denver, CO: American Water Works Association, 1984), 8-9.

- The conservation measure(s) itself
- The period over which conservation measure(s) will be implemented
- The potential market, that is, existing single-family and multifamily dwelling units and new dwelling units projected over the planning period
- Projected penetration or coverage of new and existing customers (for estimating the target population)
- Projected unit water, wastewater, and energy savings
- Projected water utility costs to implement the measure(s), including staff, materials, and incentives such as rebates and connection-fee discounts
- Customer costs to implement the alternative

Table 7-14 is a comparison of supply management and demand management along several criteria, derived from a study by the AWWA. Each management strategy has certain advantages. Supply management, for example, does not depend on consumer cooperation, is expected to be effective over the long term, and generally does not have an adverse effect on the supplier's revenues. Demand management, on the other hand, can meet long- or short-term conservation goals, can be used for low- or high-percentage reductions, and is versatile and flexible.

The AWWA states explicitly that, "Despite its costs, supply management is preferable to demand management."[41] This conclusion may rest on the fact that supply management is more within the sphere of supplier control, less dependent on consumer cooperation and, thus, more predictable in terms of outcomes. However, the bottom line may be the effect of conservation on revenues. After all, water suppliers--*public as well as private*--are in the business of selling water. Demand-side alternatives reduce consumption, which in turn may reduce revenues to the supplier. Investor-owned water utilities, particularly those with plentiful capacity, are especially sensitive to this issue. Still, the water supply industry clearly recognizes a role for demand management, particularly because of its flexibility.

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[41] Ibid., 21, at margin.

TABLE 7-14

COMPARING SUPPLY MANAGEMENT AND DEMAND MANAGEMENT PROGRAMS

Comparison Criteria	Supply Management	Demand Management
Consumer cooperation	Not dependent on consumer cooperation	Dependent on consumer cooperation
System characteristics	Can be dependent on water system characteristics	Usually not dependent on water system characteristics
Conservation goals	Meets long-term goals effectively	Can meet both long- and short-term goals
Demand problems	Suitable for average or peak demand problems due to inadequate system capacity	Solves average and peak demand problems
Speed of implementation	Usually requires a long lead time	Some can be implemented very quickly
Usage reduction goals	Best for low percentage reduction goal	Low or high percentage reduction goal
Long-term effectiveness	Expected to be high	May diminish over time
Flexibility	May still require demand management during emergencies	Versatile and flexible
Predictability	Higher	Lower
Expense	Sometimes requires large expenditures	Can require large or small expenditures
Operating costs	Can be reduced	Not necessarily affected
Labor requirements	Usually large	Can be small or large
Impact on revenues	Lost revenues can be recovered	Some programs cause revenues to drop
AWWA assessment	Preferable	Not preferable

Source: Authors' construct from American Water Works Association, *Before the Well Runs Dry: Volume I--A Handbook for Designing a Local Conservation Plan* (Denver, CO: American Water Works Association, 1984), 21-23.

Most conservation plans combined supply and demand management strategies to some degree. Conservation programs may vary in aggressiveness, as illustrated in table 7-15. The aggressiveness of the conservation program generally will be a function of water needs, infrastructure, and local culture. A moderate approach relies on such measures as revisions to the plumbing code for new housing, public information, and repairs of reported leaks. An aggressive program adds the encouragement of more efficient landscaping and wastewater reuse, active leak detection and repair, and the delivery of retrofit kits to customers. The maximum program calls for increasing block or seasonal rates, pressure reduction, and working with individual commercial and industrial customers to reduce their water use.

Benefits and Costs of Water Conservation

One way to evaluate alternative conservation programs is through a comparison of benefits and costs. Increased expenses by suppliers and sometimes users are associated with most supply and demand management measures. The issue is whether the associated benefits make the expense worthwhile.

Several states and communities have analyzed benefits and costs of water conservation programs.[42] The Arizona Department of Resources used the approach to set water conservation goals for water providers to meet in the 1990s in compliance with the Arizona Groundwater Management Act. The South Florida Water Management District analyzed the benefits and costs of conservation programs in typical south Florida cities. In Antioch, California, the method was used to develop a comprehensive water conservation program and recommend additional annual expenditures of $72,000 to reduce water demand 13 percent by the year 2005. The city of Austin, Texas used a similar analysis to prepare a long-range water management plan.

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[42] Peter P. Macy and William O. Maddaus, "Cost-Benefit Analysis of Conservation Programs," *American Water Works Association Journal* 81, no. 3 (March 1989): 45.

TABLE 7-15

WATER CONSERVATION PROGRAM ALTERNATIVES

Program Element	Type of Program Moderate	 Aggressive	 Maximum
New Housing			
Inside house	Plumbing code requires water-conserving fixtures	Same as minimum plus active enforcement	Requires advanced water-saving fixtures
Outside house	(none)	Encourage low water-use landscaping, efficient irrigation	Require low water-use landscaping, efficient irrigation, and special designs for new developments
Existing Housing			
Inside house	Retrofit kits available for pick up	Retrofit kits delivered to customer	Require installation of good equipment at specified time
General	Public information	Public education	Very active public education
Utility Actions			
Metering	All customers	All customers	All customers
Pricing	Recover all costs	Uniform pricing	Increasing block or seasonal rates
Pressure Reduction	Plumbing code minimum requirement	Control maximum pressure by zone	Regulate pressure to 50 psi in new subdivisions
Leak detection	Repair leaks reported.	Active water auditing, leak detection and repair	Aggressive and repetitive auditing, detection/repair, and customer leak-detection service
Wastewater reuse	(none)	Encourage where cost-effective	Maximize wastewater reuse
Reduce commercial/ industrial use	(none)	Provide general information	Work with individual users

Source: Adapted from Brown and Caldwell, *Residential Water Conservation Projects*, *Summary Report* (Washington, DC: U.S. Department of Housing and Urban Development, 1984), 3-3.

Most analysts are convinced that substantial benefits, relative to costs, can be achieved by implementing water conservation measures.[43] The evidence suggests that the payback period for many water-saving devices may be short, although this is not the case for some of the higher-priced vacuum toilets. Some devices, such as faucet aerators, are both inexpensive and simple for the homeowner to install. Others require professional installation with additional costs. Analyses must take into account all costs as well as who will bear them.

The two general categories of costs are those that are borne by water suppliers and those that are borne by water users. Three general categories of savings are water supply, wastewater treatment, and energy. Water supply costs are fairly straightforward, assuming that water suppliers routinely evaluate per-unit variable supply costs. Every quantity of indoor water conserved corresponds to a reduction in wastewater by the same quantity. Savings in wastewater treatment can be estimated from past experience with variable costs. Energy savings from water conservation are somewhat harder to assess, but more and more analysts recognize their importance when calculating benefits and costs.

Energy savings from water conservation for both suppliers and users can be substantial. According to one study, every 1,000 gallons of water delivered requires a total of 2.6 kilowatt-hours (kWh) of energy as follows: .9 kWh for transport, .4 kWh for treatment, .6 kWh for distribution, and .7 kWh for wastewater treatment.[44] Heating the same amount of water requires 185 kWh. On a daily per capita basis, these requirements translate to .4 kWh for water delivery and another 6.1 kWh for water heating. Naturally, reducing the amount of water used--particularly hot water--reduces energy costs. Moreover, water heating savings directly benefit consumers.[45]

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[43] Duanne D. Baumann, et al., *Planning and Evaluating Water Conservation Measures* (Chicago: American Public Works Association, 1981).

[44] F. B. Roberts and R. M. Hagan (1977) as reported in Maddaus, *Water Conservation*, 36.

[45] Of course, this implies a reduction of demand for gas or electricity for water heating. Depending on the capacity and variable costs of these providers, and perhaps their own conservation programs, this effect may be viewed as positive or negative.

Table 7-16 reports costs and savings from three community water conservation programs, as well as a national case. Each demonstrates net benefits of conservation relative to the costs of the program to water suppliers. For the national case, conservation expenditures of $2.05 were estimated to have saved a total of $19.70 in water supply, wastewater treatment, and energy costs. Thus, net savings were $17.65 and the ratio of benefits to costs was 9.6:1. The ratio of benefits to costs ranges from 5.2:1 to 50.8:1 for the three communities. Even acknowledging the uncertainty of the estimation process, the ratios suggest consideration of conservation strategies.

TABLE 7-16

COSTS AND SAVINGS OF WATER CONSERVATION

Benefits and Costs	National	Manteca	Tucson	Carbondale
	*In Millions of Dollars, Present Worth**			
Cost of Program	$2.05	$ .26	$5.27	$ .12
Savings from Program				
Water supply	3.99	.04	5.59	.26
Wastewater treatment	7.65	.08	7.68	3.34
Energy	8.06	3.00	14.24	2.40
Total Savings	19.70	3.13	27.51	6.00
Analysis of Costs & Savings				
Net Benefits	17.65	2.87	22.24	5.88
Benefit-Cost Ratio	9.6:1	11.9:1	5.2:1	50.8:1

Source: "An Evaluation Framework for Assessing Variations in the Costs and Benefits of Municipal Water Conservation," *INTASA Report to the Office of Water Research and Technology* (Washington, DC: U.S. Department of the Interior, 1981) as reported in Brent Blackwelder and Peter Carlton, *Survey of the Water Conservation Programs in the Fifty States: Model Water Conservation Program for the Nation* (Washington, DC: Bureau of Reclamation, U.S. Department of the Interior, 1982), 11.

* Numbers may be affected by rounding

Table 7-17 compares water and energy savings data for specific conservation measures, as well as their cost. Also noted are the expected rates of market penetration and water utility costs for a community of 50,000 people. The first seven measures require additional capital expenditures by homeowners, but no utility expenditures. Most produce significant savings in both water and energy. Some measures, such as drip irrigation systems, may require expenditures by both suppliers and users. Some programs, such as water audits for single-family households may be potentially costly to the water supplier, although the potential water and energy savings are great.

A final comparison of costs and savings from water conservation programs is provided in table 7-18. The table summarizes seven water supplier conservation plans, each with progressively more components. Each has a public education component, although the more comprehensive plans include advanced water fixtures for both retrofitting and new construction. The cost predictably increases with the addition of components. The savings also increase, but at a lesser rate.

For every program--even those requiring a significant supplier investment--savings outweigh costs. With the exception of the second plan, the ratio of savings to costs declines as plans include more components. The ratio of *additional* savings to *additional* costs also declines. Thus, when maximum water conservation is absolutely essential, it may make sense to invest in a broad-based conservation program. Absent this pressure, water managers may be more comfortable with a moderate plan that has a higher benefit-to-cost ratio. For most suppliers, however, a moderate conservation program should yield substantial savings in terms of water and dollars.

However important, a benefit-cost analysis for a water conservation plan should not overshadow considerations that are not easily quantified. These include effects on the hydrologic cycle (especially reductions in return flows), environmental impacts, institutional barriers, compatibility with long-term supply plans and regional water resource plans, and perhaps most important, social acceptability.

TABLE 7-17

COSTS AND SAVINGS IN WATER AND ENERGY FOR ALTERNATIVE CONSERVATION MEASURES

N	Type of Conservation Measure	Daily Water Savings in GPCD(a)	Annual Energy Savings in TPCA(b)	Addtl. Capital Costs/ Dwelling Unit(c)	Estimated Market Penetration: Pct. New Cust.	Estimated Market Penetration: Percent Existing By Year 2005	Total Util. Costs Per Year (d)
1	3.5-gallon/flush toilet	8.0	0.0	0.0	-	-	-
2	1.5-gallon/flush toilet	16.0	0.0	100.0	-	-	-
3	2.75-gpm shower head	7.2	12.0	0.0	-	-	-
4	2.00-gpm shower head	9.1	15.0	10.0	-	-	-
5	Low-use dishwasher	1.0	2.9	40.0	-	-	-
6	Low-use clothes washer	1.7	2.7	50.0	-	-	-
7	Insulate hot water pipes	2.0	5.8	200.0	-	-	-
8	Retrofit devices	16.0	12.0	2.8	0	48	$19,608
9	Retrofit on resale	16.0	12.0	19.6	0	60	10,000
10	Water audit, single fam.	24.0	12.0	0.0	0	75	40,000
11	Water audit, multifamily	20.0	12.0	23.5	0	90	13,000
12	Effic. irrig., sing. fam.	7.5	0.0	0.0	50	13	50,250
13	Effic. irrig., multifam.	3.7	0.0	0.0	50	13	12,280
14	Drip irrig., single fam.	2.0	0.0	200.0	25	20	5,000
15	Drip irrig., multifamily	1.0	0.0	100.0	50	20	2,000
16	Effic. landscape, s. fam.	20.1	0.0	0.0	25	8	50,000
17	Effic. landscape, multi.	9.8	0.0	0.0	25	8	25,000
18	Public education	4.0	0.0	0.0	100	100	25,000
A	Measures 1 and 3	15.2	12.0	0.0	100	25	-
B	Measures 2,4,5,6, and 7	29.8	26.4	400.0	15	0	7,500

Source: Adapted from Brown and Caldwell (1986) as reported in William O. Maddaus, *Water Conservation* (Denver, CO: American Water Works Association, 1987), 24-25.

(a) Gallons per capita daily.
(b) Therms per capita annually.
(c) These are capital costs *in addition* to typical costs.
(d) Based on estimates for a city of 50,000 people.
(-) No utility involvement is assumed.

TABLE 7-18

COSTS AND SAVINGS OF ALTERNATIVE CONSERVATION PROGRAMS

Water Conservation Practice and Costs and Savings *	Alternative Conservation Programs (1)	(2)	(3)	(4)	(5)	(6)	(7)
Public education	X	X	X	X	X	X	X
Retrofit devices							
Displacement bottles	-	X	-	-	-	-	-
Shower flow restrictors	-	X	-	-	-	-	-
Toilet dams	-	-	X	X	X	X	X
Shower heads	-	-	X	X	X	X	X
Water-efficient appliances	-	-	-	X	X	X	X
Pipe insulation	-	-	-	-	X	X	X
Faucet aerators	-	-	-	-	-	X	X
Pressure regulators	-	-	-	-	-	X	X
Devices for new construction							
Low-flush shower heads	-	X	X	X			
Low-flush toilets	-	X	X	X	X	X	
Pipe insulation	-	-	-	X	X	X	X
Water-efficient appliances	-	-	-	X	X	X	X
Air-assisted showers	-	-	-	-	X	X	X
Faucet aerators	-	-	-	-	X	X	X
Pressure regulators	-	-	-	-	-	X	X
Air-water toilets	-	-	-	-	-	-	X
Annual cost in dollars	0.6	0.9	3.9	9.1	40.0	46.0	75.0
Projected annual savings							
Utility operating	7.0	12.0	16.0	18.0	20.0	22.0	26.0
Residential water heating	12.0	21.0	38.0	53.0	68.0	69.0	69.0
Total savings in dollars	19.0	33.0	54.0	71.0	88.0	91.0	95.0
Ratio of savings to costs	31.7	36.7	13.8	7.8	2.2	2.0	1.3
Ratio of additional savings to additional costs	--	46.7	7.0	3.3	.55	.50	.14

Source: Adapted from American Water Works Association, *Water Conservation Management* (Denver, CO: American Water Works Association, 1981), 19-20 and author's calculations.

* Estimates of costs and savings assume individual households of three persons using 170 gallons per day per person.

Social Acceptability of Water Conservation

The wise use of water does not come naturally, but depends on a foundation of social acceptability:

> A particular water conservation measure may be technically possible, effective, and economically efficient, and yet when proposed, be rejected. In an effort to understand why, an investigator might discover that the measure had been perceived by the public or by the city council or other community powers as violating the rights of private property, or as unfairly placing the heaviest economic burden on those least able to pay, or as interfering with the prerogatives of local government, etc., etc. In realistically assessing the chances a given measure of conservation has of being implemented, it is but a short distance from the familiar concepts and methods of technical and economic considerations to the alien territories of values, beliefs, attitudes and feelings--of what may be termed "social ideologies."[46]

Evaluating social acceptability may be difficult, but it is not impossible. One study recommends combining interviews with expert advisors and a survey questionnaire for the general public.[47] While this approach does not guarantee an accurate prediction of social acceptability, it should help enlighten the decisionmaking process. With no assessment of acceptability, the risk of overestimating the effectiveness of conservation measures is greater.

When asked, many consumers express support for conservation measures. A majority of consumers in northeastern Colorado supported installing toilet dams, limiting lawn size, imposing watering restrictions, and reusing water for irrigation. An overall majority supported metering, but the majority of flat-rate customers prefer flat rates. A slight majority even supported higher prices to encourage conservation, with those having higher incomes and more education being more likely to favor this method.

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[46] Baumann, et al., *Planning and Evaluating Water Conservation Measures*, Appendix A, 59.

[47] Ibid.

The only method opposed by a majority of customers, not surprisingly, was reuse of water for drinking purposes. Support for this measure likely will depend on substantially increasing the public's faith in the feasibility of treatment technologies that make reuse possible. Authors J. Ernest Flack and Joanne Greenberg conclude that the survey is reasonably representative of Western states water users, and that water supply managers can expect public support for water conservation programs. Suppliers can cultivate support for their programs by using an intensive public education program.[48]

A survey of customers in southern Texas produced similar results. Eighty percent answered that they had reduced their overall water consumption. The results on specific consumption areas indicate that outdoor use frequently was the target of reduction. Respondents also were found to be highly supportive of state-mandated conservation plans and city-mandated conservation measures for residential and industrial use. Like their Colorado counterparts, the Texans were relatively supportive of rate increases for conservation purposes, but highly supportive of lifeline rates for water service.[49]

Finally, a recent survey prepared for the Kentucky-American Water Company revealed that the public was both aware of the potential for future water shortages and supportive of conservation, at least to a degree.[50] The findings indicated more support for conservation than for building new facilities. According to James G. Hougland, Jr., who conducted the survey, the appreciable level of support for conservation will make it easier to mobilize support for conservation. Further, he suggests that, "Because of the political context in which public utilities operate, this potential for mobilization should not be ignored as new decisions about the provision of water are made."[51]

One area of uncertainty is whether customers will be willing to make major and permanent lifestyle changes in the interest of water conservation.

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[48] Flack and Greenberg, "Public Attitudes Toward Water Conservation," 46-51.
[49] Olsen and Highstreet, "Socioeconomic Factors," 59-68.
[50] James C. Hougland, Jr., "Public Reactions to Drought and Future Water Supply Needs: Results from Public Opinion Polls," presented at the Mid-America Regulatory Conference in Chicago, Illinois (June 26, 1989).
[51] Ibid., 12.

Studies indicate that how the public responds to conservation programs and activities depends a great deal on their perceptions. During drought periods, people have an empirical basis--persistent dry weather--for believing in the prospect of water scarcity. This disappears during normal-weather periods. Thus the implementation of long-term conservation strategies may hinge on perceptions about whether a water crisis is imminent and whether conservation and wise use is the appropriate response.

Only a few years ago, articles that advocated the use of water-efficient fixtures concluded with lists of the barriers to their actual development and application.[52] *Technical* barriers included insufficient operational and performance data, unconventional physical characteristics, and uncertainties about waste transport. *Economic* barriers included high capital and potentially high operation and maintenance costs, limited production and availability, and lack of government funding for development. *Regulatory* barriers included nonconformance with plumbing codes and institutional resistance to change. *Social* barriers included actual or perceived adverse effects, limited public awareness, and resistance to change. Today, valuable data on the performance of conservation strategies are available and formerly exotic measures are gaining acceptance among water managers and water consumers. Gradually, many of the barriers to implementation are being overcome.

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[52] Robert L. Siegert, "Minimum-Flow Plumbing Fixtures," *American Water Works Association Journal* 75, no. 7 (July 1983): 342-347.

CHAPTER 8

RATEMAKING AND REGULATORY ISSUES

Water scarcity calls for new ways of managing water resources, including new ways of regulating public water suppliers. Central to regulation by the state public utility commissions is determining the appropriate price for water. Price is also central to conservation and wise use. As has been noted, water is a value-added commodity. The value of publicly supplied water derives almost entirely from withdrawal, treatment, and distribution. Sandra Postel of the Worldwatch Institute is one of several analysts who contend that inadequate pricing by suppliers has contributed to the inefficient use of water and stifled the adoption of innovations and supply alternatives that would help avert a water crisis:

> Investments in water efficiency, recycling, and conservation can increasingly yield more usable water per dollar than can conventional water supply projects. But their potential is severely undermined by pricing policies and water laws that encourage inefficiency and waste. Removing these institutional barriers is crucial in order to expand the many new water-conserving methods now in limited use. Only by managing water demand, rather than ceaselessly striving to meet it, is there hope for a truly secure and sustainable water future.[1]

In a 1982 survey of state water conservation programs, the authors of one study commented that, "The category in which there was the least effort statewide was in reform of rate structures."[2] At the time of the survey, none of the states had actually implemented conservation pricing as part of their water conservation programs. Massachusetts and Pennsylvania reported that they had partially used rate structures in their programs. Five other states (California, Maryland, Minnesota, Missouri, and Oregon) had enacted studies or proposed state policies for the use of rate structures for conservation purposes. The jurisdiction of state public utility commissions over rate structures and the lengthy process of rate reform were cited as the principal reasons for the limited attention to conservation pricing by the states in general relative to other policy alternatives.

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[1] Sandra Postel, "Increasing Water Efficiency," in Lester R. Brown, et al., *State of the World 1986* (New York: W. W. Norton and Co., 1986), 41.

[2] Brent Blackwelder and Peter Carlson, *Survey of the Water Conservation Programs in the Fifty States* (Washington, DC: Bureau of Reclamation, U.S. Department of the Interior, 1982), 3. For a summary of the findings, see chapter 7.

Clearly, the interrelated issues of pricing, conservation, and assuring future supplies are working their way onto the agendas of water resource regulators, including state public utility commissions. Although the emphasis in this chapter is on the regulatory process for jurisdictional investor-owned water utilities, the issues are equally relevant for publicly owned systems.

Water Pricing

Investor-owned water utilities are regulated to one degree or another in forty-six states.[3] Although specific authority varies, state commission regulation of water utilities is governed by the fundamental principles that govern commission regulation of all public utilities. These principles encompass such lofty goals as safe, adequate, reliable, and least-cost service; just, equitable, and reasonable rates; prudent investments and management; used and useful properties; fair rates of return; and, above all, regulation in the public interest. In times of scarcity or not, these principles apply.[4] Conditions of scarcity or perceptions of scarcity, however, place additional demands on the regulatory system.[5]

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[3] Janice A. Beecher and Ann P. Laubach, *1989 Survey on State Commission Regulation of Water and Sewer Systems* (Columbus, OH: The National Regulatory Research Institute, 1989).

Although the state commissions perform many functions, their central role is ratemaking, the process through which the costs of providing utility service are allocated to customers. Several ratemaking objectives for water utilities can be identified:[6]

- *Financial sufficiency*--generating sufficient revenues to recover operating and capital costs.
- *Conservation*--encouraging customers to make efficient use of scarce water resources.
- *Equity*--charging customers or customer classes in proportion to the costs of providing service to customer groups.
- *Implementation*--having the capability to implement the rate structure efficiently without incurring unreasonable costs associated with reprogramming, procedures modification, and redesigning forms.
- *Compliance with appropriate legal authorities*--being consistent with existing local, state, and federal ordinances, laws, and regulations.
- *Effect on customer classes*--minimizing financial effects on utility customers.
- *Long-term rate stability*--producing rates that are reasonably constant from year to year, i.e., the methodology does not produce rates that fluctuate widely from one period to another.

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[4] For example, the Illinois Public Utilities Act (Illinois Statutes, Chapter 111 2/3), authorizing legislation for the Illinois Commerce Commission, reads in part as follows: "The General Assembly finds that the health, welfare and prosperity of all Illinois citizens require the provision of adequate, efficient, reliable, environmentally safe and least-cost public utility services at prices which accurately reflect the long-term cost of such services and which are equitable to all citizens."

[5] On the other hand, the electricity, natural gas, and telecommunications industries have at times demonstrated how conditions of abundance, or "excess capacity," can place additional demands on regulators as well.

[6] George A. Raftelis, "1988 National Water Rate Survey," *American Water Works Association Journal* 80, no. 9 (September 1988): 79.

Within this context, public utility commissions set rates for water services. Determining a utility's revenues requirement and setting rates for recovering that amount can be controversial because of the many issues related to water pricing.

A 1986 workshop on water pricing and demand conducted by the Arizona Corporation Commission identified eight pricing issues upon which much attention is focused:[7]

- Relative importance of various water uses.
- Factors affecting demand--price, consumer attitudes, landscaping preferences, income, etc.
- Effect of price on water usage--theory and findings.
- Prices to which consumers respond--average prices versus marginal prices.
- Water pricing to achieve conservation and to reflect costs of water supply--theory and experience.
- Pricing mechanisms--increasing block rates, marginal-cost pricing, seasonal pricing, other.
- Consumer acceptance of innovative pricing.
- Revenue impacts on water utilities--seasonal volatility, excess or insufficient revenues, etc.

Marginal-Cost Pricing

Economic theory argues for pricing resources at marginal costs to ensure their efficient allocation. Marginal cost is the additional cost of producing or selling a single incremental unit.[8] The two components of marginal cost are: first, the change in operating costs caused by changing the rate of utilization of existing capacity and, second, the cost of expanding capacity, including the operating costs associated with increased capacity. While fully distributed costs are based on embedded historic accounting costs, the calculation of marginal costs involves projecting future operating and capacity costs for a specified time span dependent on forecast increase in the quantity demanded of the service. Such projections must take into account certain features of water utilities, such as relatively high fixed costs, health and safety regulations, and weather-sensitive usage.

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[7] Arizona Corporation Commission, "Introduction," *Water Pricing and Water Demand: Papers Presented at a Water Pricing Workshop* (Utilities Division, August 21, 1986), 2.

[8] These definitions are from Patrick C. Mann and Donald L. Schlenger, "Marginal Cost and Seasonal Pricing of Water Service," *American Water Works Association Journal* 74, no. 1 (January 1982): 6.

Prices that accurately reflect costs send correct signals to consumers and discourage wasteful consumption. Thus, marginal-cost pricing can complement the wise-use-of-water approach. Blackwelder and Carlson noted that, "Because the water saving potential of changes in rate structure is large, efforts should be undertaken at the state level or through the appropriate Public Service Commission to change to marginal cost pricing."[9]

When applying marginal-cost pricing to the water industry, four factors are important.[10] First is that water utilities typically face little competition. Second, marginal costs may be different for different ratepayer classes. Third, marginal costs can be estimated separately for commodity, capacity, and customer charges. Finally, marginal cost estimates should account for peak periods of use, normally in the warm-weather months, when costs are generally higher. Time-differentiated pricing follows the marginal-cost approach, although the two are not synonymous because seasonal rates can be based on either embedded or marginal costs.[11] Many analysts contend that marginal cost and seasonal pricing are not only more efficient, but more equitable than average-cost pricing.[12]

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[9] Blackwelder and Carlson, *Survey of the Water Conservation Programs in the Fifty States*, 4. The authors were especially impressed by the rate structure programs implemented in Montgomery and Prince Georges Counties, Maryland.

[10] Richard A. Berk, et al., *Water Shortage: Lessons in Conservation from the Great California Drought, 1976-1977* (Cambridge, MA: Abt Books, 1981), Appendix 2, 178.

[11] Mann and Schlenger, "Marginal Cost and Seasonal Pricing of Water Service," 6.

[12] Patrick C. Mann, *Water Service: Regulation and Rate Reform* (Columbus, OH: The National Regulatory Research Institute, 1981).

There may be limitations to the application of marginal-cost pricing theory.[13] There also is no unanimity on the application of the theory to water service. According to the AWWA:

> Although the economic theory behind marginal cost pricing is sound, the application of the theory to water rates lacks considerable practicality. Pricing all water at the marginal cost could result in the collection of revenue from customers considerably in excess of current needs. . . . [M]arginal cost rates have some value in theory, but their practical application needs to be thoroughly studied before adoption.[14]

Marginal-cost pricing will result in *insufficient revenues* to the water utility if average cost is more than marginal cost and *excess revenues* if average cost is less than marginal cost. Accordingly, "it may be necessary to structure customer charges to achieve a balance of revenues and costs or to diverge from marginal cost pricing somewhat" in order to align costs and revenues.[15] For these reasons, it may not be possible to obtain the *most* efficient allocation of water resources. A second-best solution may be one in which consumers either overconsume or underconsume. Moreover, it may be argued that marginal-cost pricing as a variant of usage-sensitive pricing results in a less predictable revenue stream to the water supplier.

Patrick C. Mann and Donald L. Schlenger also identify some of the problems associated with the application of marginal-cost and seasonal pricing to water service.[16] These include cost computation and forecasting, price and revenue volatility, revenue erosion, potential excess revenues, distribution effects, and the uncertain effects on costs and economic efficiency. The authors conclude, however, that these problems should not discourage the use of innovative rate structures. Mann adds that, "the major opposition to marginal cost pricing for water lies less with its underlying theory and its imprecise calculation than with rate structure design, or converting the cost estimations into actual rates."[17]

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[13] For an overview, see David Chessler and Li-Kung Ferng, "On the Limited Use of Marginal Cost Pricing in Telephone Regulation," in Jane L. Racster, ed., *Issues in Regulating Imperfectly Competitive Telecommunications Markets* (Columbus, OH: The National Regulatory Research Institute, 1986), 43-94.

[14] American Water Works Association, *Water Rates* (Denver, CO: American Water Works Association, Third Edition, 1983), 57.

[15] Mark Day, "A Discussion of Empirical Evidence of the Conservation Impact of Water Rates," in Arizona Corporation Commission, *Water Pricing and Water Demand*, 38.

[16] Mann and Schlenger, "Marginal Cost and Seasonal Pricing," 6-11.

According to Duane Baumann, there is some evidence suggesting that consumers react both to marginal prices (as measured by changes in water bills) and average prices (as measured by total water bills).[18] High marginal prices have the effect of increasing variations in total monthly bills. Marginal bill increases are tolerated until the total bill reaches some threshold amount that triggers a consumer response.

Naturally, the biggest difficulty in applying marginal-cost pricing is the estimation of marginal costs, which depends entirely on assumptions about where the next increment of supply will come from and, of course, its cost. Several different supply options, providing different increments of capacity, may be available. A new well, for example, adds a much smaller increment of capacity than a new reservoir and probably at a lower total cost. However, the per-unit costs of the reservoir may be lower than the per-unit cost of the well because of the reservoir's enormous capacity. Choosing between the two depends on the forecast of water demand.[19] It is also difficult to reconcile marginal-cost pricing with other elements of conservation programs that emphasize *decrements* rather than increments of capacity. Thus, it is generally preferable to apply marginal-cost pricing within a planning context that addresses these concerns. Otherwise, even though it is advocated as a conservation strategy, marginal-cost pricing may not be effective in preventing supply shortages or excess capacity.

Price Elasticity of Water Demand

In economics, demand is understood as the inverse relationship between price and quantity consumed within a market-like arrangement. The price elasticity of demand measures the percentage change in quantity consumed in response to a percentage change in price. Estimation of price elasticity is an important component of demand forecasting and revenue projection. If a rate change is anticipated, its effects on demand and revenues must also be anticipated by utilities and their regulators.

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[17] Ibid., iv.

[18] Duane Baumann, "Issues in Water Pricing," in Arizona Corporation Commission, *Water Pricing and Water Demand*, 9.

[19] Of course, hydrologic and water quality factors also affect the choice.

In a linear demand model, the price elasticity of demand (n) is calculated as:[20]

$$n = \frac{\text{change in quantity}}{\text{change in price}} \times \frac{\text{mean price}}{\text{mean quantity}}$$

where:

$n = 0.0$ (perfectly inelastic)
$n = 0.0 \rightarrow -1.0$ (relatively inelastic)
$n = -1.0$ (unitary elasticity)
$n = -1.0 \rightarrow -\text{infinity}$ (relatively elastic)
$n = -\text{infinity}$ (perfectly elastic)

Water, since it is used in a wide variety of ways, is likely to be characterized by a number of different demand curves and each may reflect a different elasticity factor. For some types of water use, a change in price is likely to bring about a substantial change in the quantity consumed. Water for luxuries such as swimming pools and landscapes may have elastic demand curves. By contrast, demand for water used for drinking, bathing, laundry, and other more fundamental needs may not be as likely to decrease as the price of water increases.

It is theorized, moreover, that since water is essential to life and no other good can be substituted for it, some small, essential amount of water will always have a perfectly inelastic demand--consumers will be willing to pay any price for it. Because water is necessary for survival, it has been argued that price should not be the principal method of allocation during a severe water shortage.[21]

For many water uses, however, the method of water delivery can be substituted. Drinking water, for example, can be gotten from the tap, brought home from the supermarket, or delivered in bottles. Some users can substitute publicly supplied water with water from their own wells and thus bypass the water utility. Industrial users may not require treated water in the first place. Some large users may be able to relocate to areas with water services more suited to their needs. Efficiency and conservation also are substitutes for water. Recycling, for example, substitutes used water for new withdrawals. In some instances, conservation in response to drought or other water shortages may have a permanent effect on water consumption habits.[22] These factors should be taken into account when estimating elasticities of water demand.

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[20] Ibid., 6-7.

[21] David R. Dawdy, L. Douglas James, and J. Anthony Young, "Demand Oriented Measures," in Vujica Yevjevich, Luis da Cunha, and Evan Vlachos, eds., *Coping with Droughts* (Littleton, CO: Water Resources Publications, 1983).

The principal findings about price elasticity of water demand are summarized by Patrick C. Mann:

> [A]ggregate municipal demand is relatively price inelastic; however, price elasticity appears to vary positively with water price levels; i.e., there is more usage-price sensitivity with higher rates than with lower rates. The price elasticity of residential demand is similar to aggregate municipal demand except when disaggregated into seasonal and non-seasonal components. In this case, seasonal demand generates higher price elasticities than non-seasonal demand. Finally, commercial and industrial demands appear to be more sensitive to price changes than residential demand. The price elasticity coefficients associated with water demand generally indicate that water rate changes can alter usage levels. However, the relatively low coefficients associated with residential demand along with evidence that average sprinkling demand is more sensitive to price than maximum sprinkling demand produces the conclusion that time-differentiated rates may be more effective than general rate increases in altering consumption patterns.[23]

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[22] Frank H. Bollman and Melinda A. Merritt, "Community Response and Change in Residential Water Use to Conservation and Rationing Measures: A Case Study--Marin Municipal Water District," in James E. Crews and James Tang, eds., *Selected Works in Water Supply, Water Conservation and Water Quality Planning* (Fort Belvoir, VA: Institute for Water Resources, U.S. Army Corps of Engineers, 1981), 393.

[23] Mann, *Water Service*, iii.

Several studies of price elasticity for water demand are summarized in table 8-1. The estimates vary widely. According to Baumann, the literature as a whole suggests that a likely range of elasticity for residential demand is between -0.20 and -0.40, or relatively inelastic.[24] Although its statistical significance is questionable, an estimate of elasticity for industrial demand is between -0.50 and -0.80, or somewhat more elastic than the residential sector, as expected. The implication is that industrial users will tend to reduce consumption in response to price increases by a larger quantity than the residential customer. Presumably, a large enough increase will cause some of these users to seek alternative water supplies.

As part of a comprehensive analysis of water pricing in Tucson, Arizona, William E. Martin and his associates conducted a longitudinal analysis of changes in prices and quantities of water pumped in order to assess price elasticity.[25] The results are reported in table 8-2. In eleven of sixteen years studied, they found the implied elasticity to be negative, as would be expected. While people appear to respond to higher prices by cutting back their consumption, the authors concluded that major cutbacks can only be expected when the rate increase is accompanied by enough publicity to increase public awareness. Further, price is only one of several variables, including weather, that appear to significantly affect consumption. In periods of drought, changes in water practices, perhaps brought about by public information campaigns, may actually prove to be more influential than the simple price-quantity relationship.

Conservation and Revenue Shortfalls

Conservation of supplies does not alter water use and its effects on utility revenues are generally limited. More accurate metering may actually increase revenues. Many other supply management measures (such as leak detection and repair) may "pay for themselves" by reducing utility expenses

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[24] Baumann, "Issues in Water Pricing," in Arizona Corporation Commission, *Water Pricing and Water Demand*, 7.

[25] William E. Martin, et al., *Saving Water in a Desert City* (Washington, DC: Resources for the Future, 1984).

TABLE 8-1

ESTIMATED PRICE ELASTICITIES FOR WATER DEMAND

Investigator	Year	Type of Analysis	Price Elasticity
Gottlieb	1952	68 Kansas cities	-1.02
	1952	19 Kansas cities	-1.24
	1957	84 Kansas cities	-0.69
	1957	24 Kansas cities	-0.68
	1958	24 Kansas cities	-0.66
	1963	Kansas cross-sectional	-0.95 (mean)
Seidel and Baumann	1957	American cities, cross-sectional at $.45/1000 gal	-0.12
Renshaw	1958	36 water service systems, cross-sectional	-0.45
Fourt	1958	34 American cities, cross-sectional	-0.39
Heaver and Winter	1963	Ontario cities	-0.254
Wong, et al.	1963	Northeastern Illinois, cross-sectional	-0.31 (mean)
Hedges and Moore	1963	Northern California irrigation	-0.19
Howe & Linaweaver	1963-65	21 residential domestic	
		Public sewers	-0.23
		Seasonal use	-1.16
Gardner and Schick	1964	42 northern Utah water systems, cross-sectional	-0.77
Flack	1965	54 Western cities, cross-sectional at $.45/1000 gal	-0.12
		All cities at $.45/1000 gal	-0.65
Ware and North	1965	634 Georgia residences	-0.67
Bain, Caves, & Margolis	1966	41 northern California cities	-1.10
		Irrigation	-0.64
	1966	41 California cities, cross-sectional	-1.099
Conley	1967	24 southern California communities, cross-sectional	-0.625 (mean)
Bruner	1969	Phoenix	-0.33
Turnovsky	1969	19 Massachusetts towns, cross-sectional	-0.225 (mean)
	1969	Industrial Massachusetts, cross-sectional	-0.47 to -0.84
Burns, et al.	1970s	Stratified two-price comparison	
		In house	-0.20 to -0.38
		Sprinkling	-0.27 to -0.53
Grima	1970	91 observations, cross-sectional	-0.93
Wong	1970	Chicago, 1951-61, time series	-0.15 (mean)
		Four large groups, cross-sectional	-0.54 (mean)

TABLE 8-1--Continued

Investigator	Year	Type of Analysis	Price Elasticity
Ridge, R.	1972	Industrial, cross-sectional	
		Malt liquor	-0.3
		Fluid milk processing	-0.6
Wong	1972	Ontario cities, winter	-0.75
Young, R.A.	1973	Tucson time-series, 1946-71 (reanalysis)	-0.20
DeRooy	1974	New Jersey chemical, cross-sectional	
		Cooling	-0.89
		Processing	-0.74
		Steam generation	-0.74
Grunewald, et al.	1975	150 rural Kentucky cities, cross-sectional	-0.92
Hogarty & McCay	1975	Blacksburg, Va., 2-year time series	-0.50 to -1.40
Pepe, et al.	1975	4 South Carolina cities, 2- and 3-year time series	0.00 to -0.51
Camp, R.C.	1978	228 Mississippi households, cross-sectional	-0.24 to -0.31
Carver, P.H.	1978	13 Washington, D.C. utilities 6-year time series, cross-sectional (short run)	0.00 to -0.1
	1978	Fairfax County, VA, 4-year time series of an innovative price structure	-0.02 to -0.17
Lynne, et al.	1978	Miami, Fla., cross-sectional	
		Department stores	-0.33
		Grocery stores	-0.89
		Hotels	-0.14 to -0.30
		Eating and drinking (not significantly different from zero)	---

Source: U.S. Army Corps of Engineers as adapted by William O. Maddaus, *Water Conservation* (Denver, CO: American Water Works Association, 1987), 66.

TABLE 8-2

PRICE ELASTICITIES FOR TUCSON, ARIZONA

Fiscal Year (a)	Percentage Change in Price (b)	Percentage Change in Quantity (c)	Implied Price Elasticity of Demand (d)	Direction of Change
1966-1967	-2.8	-1.6	+.57	P↓ Q↓
1967-1968	-2.7	+3.0	-1.11	P↓ Q↑
1968-1969	-3.9	+2.8	-.72	P↓ Q↑
1969-1970	-5.3	+4.0	-.75	P↓ Q↑
1970-1971*	+17.9	-3.7	-1.2	P↑ Q↓
1971-1972	-4.1	-1.5	+.37	P↓ Q↓
1972-1973	-3.1	-7.3	+2.35	P↓ Q↓
1973-1974	-6.0	+19.8	-3.30	P↓ Q↑
1974-1975*	+40.6	-13.1	-.32	P↑ Q↓
1975-1976	-8.4	+6.8	-.80	P↓ Q↑
1976-1977*	+21.3	-16.6	-.78	P↑ Q↓
1977-1978*	+23.8	-4.9	-.21	P↑ Q↓
1978-1979*	0.0	-1.7	undefined	P→ Q↓
1979-1980*	-3.8	+6.4	-1.68	P↓ Q↑
1980-1981*	-7.9	+2.9	-.37	P↓ Q↑
1981-1982*	0.0	+4.2	undefined	P→ Q↑

Source: William E. Martin, et al., *Saving Water in a Desert City* (Washington, DC: Resources for the Future, 1984), 67.

(a) * Indicates years in which a new price schedule was introduced.
(b) Based on change in real prices between years using 1979 dollars.
(c) Based on change in pumpage between years.
(d) The implied price elasticity of demand: %ΔQuantity/%ΔPrice.

related to withdrawal, treatment, or distribution. If this is not the case, the expenses associated with supply management may reduce the supplier's profit margin and trigger a request for a rate increase. In general, however, there is more concern for the revenue effects of demand management and, in particular, conservation pricing.

Because it tends to induce conservation, a price increase is often viewed as a potential demand management tool. Elasticities determine how much conservation occurs in response to a price change. In some cases, conservation may occur "naturally" as prices edge upward due to increased costs and consumers make adjustments along the way in the form of increased efficiency in water fixtures and changes in behavior.[26] This form of conservation does not necessarily result in a revenue loss to the water supplier. In other cases, sharp price increases may induce sudden demand reductions by moving consumers into an elastic part of the demand curve. Another price increase to remedy this revenue shortfall may not be appropriate because it may lead to further revenue reductions.

When conservation measures or water use prohibitions are in full force, absent an accompanying rate increase, utility revenues will be reduced. A revenue shortfall may make it difficult for some utilities to cover their fixed costs. The revenue effects of nonprice conservation are shown in the no-growth hypothetical model presented in table 8-3. According to this model using typical elasticity estimates, doubling the price of water results in a 32 percent reduction in demand but a 36 percent increase in revenue for the water utility.[27] Without a price increase, the revenue loss caused by the same level of conservation would be about $585,000 (32 percent).

Since conservation can have an adverse effect on utility revenues, it may be necessary to effect a price increase when implementing a nonprice conservation strategy, such as a retrofit program, to meet the water supplier's revenue requirements. Thus a careful consideration of price is critical to *any* utility conservation effort, even if price itself is not the principal conservation tool.

Conservation through pricing can be an effective tool for managing demand when the objective is to avoid the need for additional capacity. In 1977, Dallas became one of the first major cities to adopt a pricing policy that imposes a surcharge on peak residential use, as reported in table 8-4. Although large peak-time users (more than 20,000 gallons in the summer) experienced a 58 percent rate increase, the overall increase in revenue

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[26] Darryll Olsen and Allan L. Highstreet, "Socioeconomic Factors Affecting Water Conservation in Southern Texas," *American Water Works Association Journal* 79, no. 3 (March 1987): 68.

[27] J. Ernest Flack, "Increasing Efficiency of Non-Agricultural Water Use," in Ernest A. Engelbert and Ann Foley Scheuring, eds., *Water Scarcity: Impacts on Western Agriculture* (Berkeley, CA: University of California Press, 1984), 147.

TABLE 8-3

HYPOTHETICAL MODEL OF ELASTICITY EFFECTS ON UTILITY REVENUES

Residential Demand Sector (a)	Daily Demand in Million Gallons at $.43 per 1,000 Gallons	Assumed Elasticity (b)	Daily Demand in Million Gallons at $.86 per 1,000 Gallons	Difference	
				Million Gallons	Per-cent
Household	1.92	-0.225	1.49	(.43)	-22%
Sprinkling	2.35	-0.395	1.42	(.93)	-40
Total	4.27	-	2.91	(1.36)	-32
Utility revenues with rate increase ($.43 → $.86)	$1,836,100	-	$2,502,600	$666,500	+36
Utility revenues with no increase	$1,836,100	-	$1,251,300	$(584,800)	-32

Source: Adapted from J. Ernest Flack, "Increasing Efficiency of Nonagricultural Water Use," in Ernest A. Engelbert and Ann Foley Scheuring, eds., *Water Scarcity: Impacts on Western Agriculture* (Berkeley, CA: University of California Press, 1984), 146-47.

(a) A population of 30,000 (10,000 households) is assumed.
(b) Based on literature estimates.

TABLE 8-4

DALLAS RATE STRUCTURE CHANGE TO PROMOTE WATER CONSERVATION

User's Monthly Consumption	Old Rate (a) $/1000 gal	New Rate (b) $/1000 gal	Percentage Increase
First 8,000 gallons	.58	.61	5%
8,001 - 20,000 gallons	.50	.61	22%
Over 20,000 gallons (October-May)	.50	.61	22%
Over 20,000 gallons (June-September)	.50	.79	58%
Overall increase in revenue requirement	-	-	12%

Source: I. M. Rice and L. G. Shaw, "Water Conservation--A Practical Approach," in American Water Works Association, *Water Conservation Strategies* (Denver, CO: American Water Works Association, 1980), 73.

(a) Rates effective before January 1977.
(b) Rates effective after January 1977.

requirements was 12 percent. A preliminary assessment attributed a reduction in demand to the then-new pricing system, with water savings equivalent to the construction of a 50 to 75 million-gallons-per-day treatment plant *at no cost.*[28]

The elasticity of water demand is an important measure, but it does not encompass all the variables that may affect water consumption behavior and reactions to price changes. As prices escalate, affordability becomes an issue for water service as it does for all public utilities. Price increases also bring about political reactions that may affect ratemaking and other regulatory processes. Thus estimates of elasticities and their effects cannot be made in a vacuum.

In the abstract, public support for using metering and rates to induce conservation is fairly high.[29] However, the public and government officials may be particularly sensitive to rate hikes that are imposed at the same time consumers are being asked to conserve, even if new rates are required to recoup utility losses from reduced sales. David W. Prasifka quotes a state legislator as saying, "It's like asking someone to help you lift a heavy load and then picking his pockets when his hands are busy."[30]

Water Rate Structures

The simplest way to bill customers for water service is to use a flat rate through which all are charged the same amount for service regardless of usage levels. No metering is required and fees may be collected according to any desired schedule, even annually. Flat rates can be cost-based to a degree because relatively high fixed costs characterize the water supply industry. They also insulate utilities from fluctuations in use caused by weather or other factors. However, most analysts reject the idea of flat rates because they send no price signals to customers to reflect the value of water service. Nor do they provide an incentive to conserve. Flat rates, in fact, tend to encourage waste.

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[28] I. M. Rice and L. G. Shaw, "Water Conservation--A Practical Approach," in American Water Works Association, *Water Conservation Strategies* (Denver, CO: American Water Works Association, 1980), 73.

[29] J. Ernest Flack and Joanne Greenberg, "Public Attitudes Toward Water Conservation," *American Water Works Association Journal* 79, no. 3 (March 1987); and Olsen and Highstreet, "Socioeconomic Factors."

[30] David W. Prasifka, *Current Trends in Water-Supply Planning* (New York: Van Nostrand Reinhold Company, 1988), 160.

Metering itself facilitates conservation. The Brown and Caldwell analysis emphasizes, as do other studies, that the principal effect of water metering is to reduce landscape irrigation, and reduce warm-weather usage.[31] Thus metering may have the effect of lowering peaking factors. Customers with meters can be billed according to different rate structures, many of which are illustrated in table 8-5.[32]

The simplest rate structure for metered customers is the uniform rate, under which all customers are charged the same amount for every unit of water consumption. Because the rate does not provide a volume discount, and customers can contain their total bill by avoiding excessive use, uniform rates provide an incentive to conserve.

Decreasing (or declining) block rates, by comparison, provide a discount for large volume use. Proponents of declining block rates argue that large users are entitled to lower per-unit prices because of the economies of scale in serving them. Ramsey pricing theory would argue that these customers should get a price break because their demand is more elastic, and reasonable substitutes may entice them to leave the water system. Critics argue that declining block rates encourage waste and in some cases subsidize large users. With declining block rates the incentive to conserve *declines* with greater consumption.[33]

Under increasing (or inclining) block rates, the per-unit price increases with more consumption. This rate structure is advocated as a method for reducing average and peak water usage. Large users bear the burden of costs associated with providing large quantities of water. With increasing block rates, the incentive to conserve increases with greater consumption.

The excess use charge is essentially an increasing block schedule with two blocks. It requires the determination of acceptable consumption and

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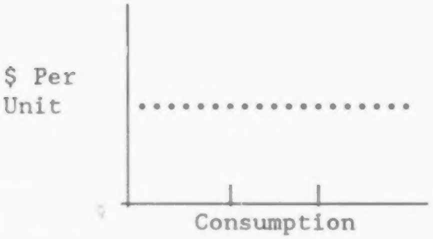
[31] Brown and Caldwell, *Residential Water Conservation Projects, Summary Report* (Washington, DC: U.S. Department of Housing and Urban Development, 1984), 7-2.
[32] These schedules are adapted from American Water Works Association, *Before the Well Runs Dry: Volume I--A Handbook for Designing a Local Conservation Plan* (Denver, CO: American Water Works Association, 1984), 61-63.
[33] Baumann, "Issues in Water Pricing," in *Water Pricing and Water Demand*, 9.

TABLE 8-5

RATE DESIGN ALTERNATIVES

Uniform Rate

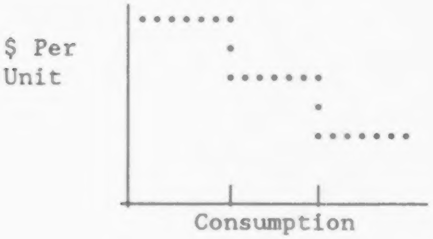


Definition: Price per unit is constant as consumption increases.

Best used for: May be somewhat effective in reducing average use.

Considerations: Large-volume users consider this structure equitable.

Decreasing Block

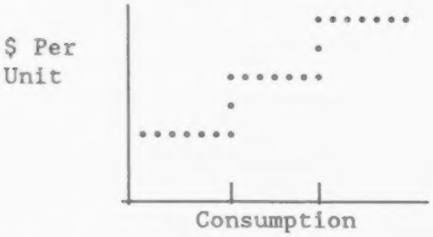


Definition: Price per unit decreases as consumption increases.

Best used for: Reducing either peak or average use.

Considerations: Large-volume users prefer this structure. When there is sufficient supply, the cost of supplying water will probably decrease as consumption increases.

Increasing Block

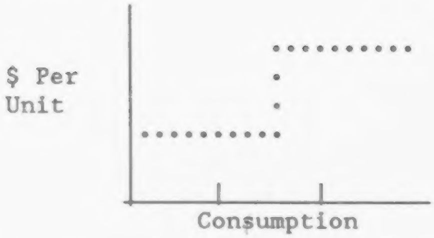


Definition: Price per block increases as consumption increases.

Best used for: Reducing average (and sometimes peak) use.

Considerations: Large-volume users consider this structure inequitable.

Excess Use



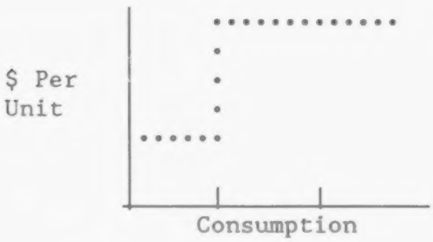
Definition: Price level is significantly higher for all water used above average, usually determined by winter use.

Best used for: Reducing peak use.

Considerations: Large-volume users consider this structure equitable.

TABLE 8-5--Continued

Lifeline Pricing

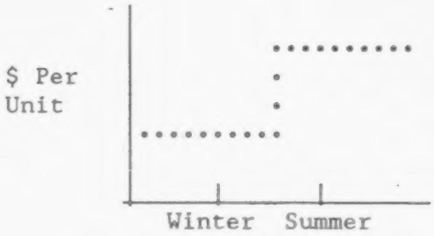


Definition: Price for "necessary" water use is kept low.

Best used for: Reducing average use.

Considerations: Usually used to insure that low-income users are not unduly burdened by high prices.

Seasonal

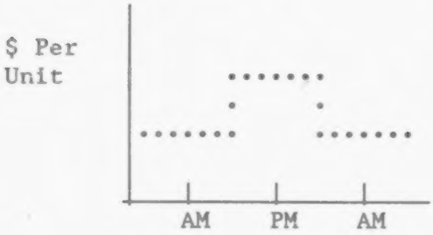


Definition: Price level during season of peak use (summer) is higher than the level during winter.

Best used for: Reducing peak use.

Considerations: Large-volume users consider equitable. Effective for summer tourist community.

Daily Peak Load

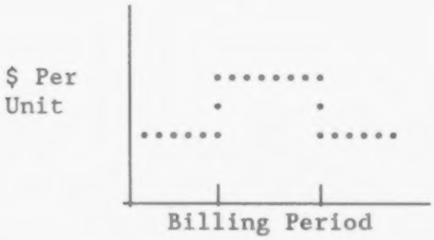


Definition: Price level is higher during hours of peak use.

Best used for: Reducing peak use.

Considerations: Expensive to implement because it requires a sophisticated water meter reading system.

Average Variable



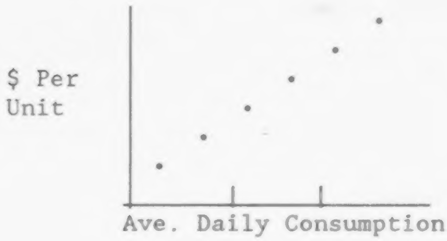
Definition: Price per unit varies according to actual expenditures during billing period.

Best used for: Does not affect use.

Considerations: Should be used *only* where costs vary significantly during billing periods.

TABLE 8-5--Continued

Sliding Scale

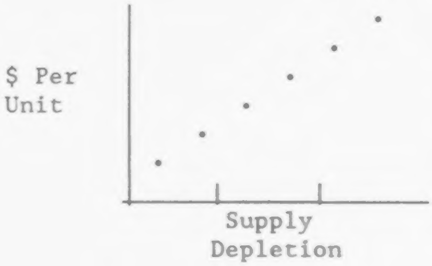


Definition: Price level per unit for all water used increases based on average daily consumption.

Best used for: Reducing average (and sometimes peak) use.

Considerations: Large volume users consider this structure inequitable.

Scarcity Pricing

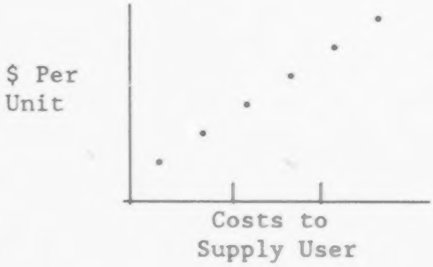


Definition: Cost of developing new supply is attached to existing use.

Best used for: Reducing average use.

Considerations: Used where supplies are diminishing (i.e., a finite supply) so that the costs for developing new supplies are paid for by current users.

Spatial Pricing

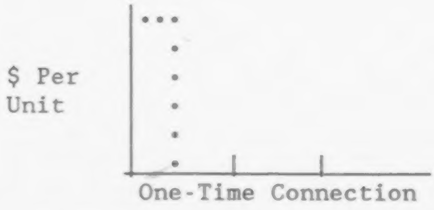


Definition: User pays for actual cost of supplying water to his establishment.

Best used for: Discouraging new or difficult to serve connections.

Considerations: Used in areas where the distribution system is being expanded rapidly and in difficult to serve areas (long mains, pumps, etc.).

Hook-Up Fees



Definition: Charge at time of connection.

Best used for: Discouraging new connections.

Considerations: Usually used to recover connection costs, if the system is nearing capacity, to discourage new hook-ups.

Source: Adapted from American Water Works Association, *Before the Well Runs Dry: Volume I--A Handbook for Designing a Local Conservation Plan* (Denver, CO: American Water Works Association, 1984), 61-63.

excess consumption, with corresponding prices. Although some consumers may view this method as arbitrary, the imposition of excess use charges or penalty fees are not uncommon during periods of water shortage, and there is evidence suggesting that the public is supportive of their use.[34]

Lifeline pricing is another variation on the increasing block theme. It provides a low per-unit price for a moderate level of consumption so that low-income consumers can receive water service for basic needs at a reasonable cost. Lifeline rates have been infrequently considered by water utilities or their regulators. This is because of the problem of cross-subsidization and the belief that lifeline policies essentially provide social welfare benefits that are more appropriately administered by governments and funded by general tax revenues.[35] As the cost of drinking water escalates, lifeline rates may receive more attention.

Seasonal and daily peak load (or time-of-day) pricing are time-differentiation methods that follow marginal-cost pricing theory. Seasonal rates impose higher prices during periods of peak use (in the warm-weather months) to recover costs associated with the higher capacity needs caused by irrigation and landscaping. Daily peak-load rates are infrequently used by water utilities because, unlike electricity, the ability to store water mitigates the daily peaking problem, the cost of water does not vary significantly on an hourly basis, and the investment required for metering under these rates could outweigh the benefits.[36]

Some rate schedules have somewhat limited applications. Average variable pricing is a variation on seasonal pricing based on a calculation of actual costs for every billing period. However, this method is only appropriate in cases where costs vary significantly in different periods. Sliding scale pricing, like increasing block rates, assigns higher prices to higher consumption levels, only prices are tied to average daily consumption rather than total consumption. Scarcity pricing stems from marginal-cost theory and assigns higher prices in accordance with the depletion of existing supplies. It may be appropriate for pricing finite water supplies where it is desirable to have current users pay for developing new supplies.

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[34] Edward F. Renshaw, "Conserving Water Through Pricing," *American Water Works Association Journal* 74, no. 1 (January 1982): 5.

[35] John F. Guastella, "Lifeline and Social Policy Pricing" in American Water Works Association, *Water Rates: An Equitability Challenge*, AWWA Seminar Proceedings (Denver, CO: American Water Works Association, 1983), 82-87.

[36] John D. Russell, "Seasonal and Time of Day Pricing," in American Water Works Association, *Water Rates: An Equitability Challenge*, 91.

Spatial pricing assigns the actual costs of service to the user. As those costs increase, so does the price of water. High prices for certain areas may discourage service expansions. Contributions in aid of construction for new developments are a form of spatial pricing. Finally, hook-up fees can be assessed to cover the cost of initiating service for new customers. If these fees are high, some prospective customers may be discouraged from connecting to the system. Spatial pricing and hook-up fees are designed to recover certain front-end costs, but must be combined with other rates to recover the ongoing costs of water service.

Despite the variety of available rate structures, most utilities use either flat rates (unmetered), uniform rates, decreasing block rates, or increasing block rates. A recent survey of 112 larger water utilities found that 36 used uniform rates, 57 used decreasing block rates, and 19 used increasing block rates.[37] Twenty-two of the utilities using decreasing block rates were located in the Midwest. Eleven of the 19 utilities using increasing block rates were located in the Southwest and West where, of course, water scarcity is a more pressing issue.

Conservation Rates

Modifying the rate schedule is a method of demand management for which water suppliers are the managing agent.[38] According to one water resource regulator, altering rate structures is a strategy distinct from the traditional "turf and toilets" approach to water conservation.[39] Although its long-term effects are less certain, raising prices may be one method of inducing water conservation in the short term. Although many of the different rate schedules reviewed above may induce conservation, some are specifically advocated for this purpose.

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[37] Raftelis, "1988 National Water Rate Survey," 79.

[38] See chapter 7.

[39] Bruce Adams, South Florida Water Management District, as quoted in *American Water Works Association Mainstream* (January 1989): 10.

Increasing block rates are frequently advocated as a method of conservation pricing and have been implemented for this purpose in several major United States cities, as reported in table 8-6. Mann cites several potential problems with increasing block rates.[40] First, they are efficient only under unique circumstances. Second, prices that are below incremental costs in the initial blocks and prices that exceed costs in the tail blocks promote neither conservation nor efficient water use. Third, like declining block rates, increasing block rates pose problems associated with determining the number of blocks, consumption breakpoints, and rate differentials. Finally, Mann concludes that a serious problem with increasing block rates is their potential impact on utility costs and revenues:

> [I]nverted block rates can cause decreasing average consumption unaccompanied by decreases in peak demands. The result is deteriorating load factors and the creating of needle peaks for the water utility. The combination of decreasing revenues and increasing unit costs can mean revenue erosion (and pressure for rate increase) as well as greater potential for revenue instability. Pressure on costs can also come from large users abandoning service (e.g., industrial firms resorting to self-supply). The cost argument underlying the inverted block form is questionable; i.e., with the incremental costs of new capacity increasing, increasing consumption and demand should be discouraged by price signals. However, the villains in this case are the contributors to peak demand who are not necessarily large users of water service.[41]

John D. Russell generally rejects the use of an increasing block rate because it "unduly penalizes large customers who may have very favorable annual consumption characteristics."[42] There also may be other factors differentiating costs that are not accounted for by an increasing block rate. According to the American Water Works Association (AWWA), "It is possible to use some elements of a cost-of-service study as a guide in the design of inverted rates."[43] Accordingly, a peak-use-period inverted-block-

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[40] Mann, *Water Service*, 98-99.

[41] Ibid., 99.

[42] Russell, "Seasonal and Time of Day Pricing," in American Water Works Association, *Water Rates: An Equitability Challenge*, 96.

[43] American Water Works Association, *Water Rates*, 58.

TABLE 8-6

MAJOR UNITED STATES CITIES USING INCREASING BLOCK RATES FOR WATER SERVICE

City, State	Effective Date(a)	Number of Blocks	Billing Cycle
Phoenix, Arizona	April 1987	3	monthly
Tucson, Arizona	May 1987	7	monthly
Bakersfield, California (b)	March 1987	2	monthly
San Diego, California (c)	July 1987	2	bimonthly
San Jose, California	July 1987	2	monthly
Ventura, California	June 1987	2	bimonthly
Jacksonville, Florida	December 1981	2	monthly
St. Petersburg, Florida	September 1987	3	not available
West Palm Beach, Florida (d)	October 1987	2	monthly
Louisville, Kentucky	January 1987	6	monthly/bimonthly
Boston, Massachusetts	April 1987	10	quarterly
Omaha, Nebraska	March 1987	3	monthly
Albany, New York	November 1983	2	triannually
Corpus Christi, Texas (d)	December 1984	6	monthly
Dallas, Texas (e)	October 1987	2-3	monthly
El Paso, Texas	March 1985	5	monthly
San Antonio, Texas (f)	September 1987	2	monthly

Source: Adapted from *Arthur Young's 1988 National Water and Wastewater Rate Survey* (Charlotte, NC: National Environmental Consulting Group, Arthur Young and Company, 1988).

(a) Effective date refers only to the rate structure in place at the time of the survey.
(b) Residential customers have a flat-rate option.
(c) Commercial customers have uniform rates.
(d) Commercial customers have declining block rates.
(e) Commercial customers have uniform rates in winter, increasing block in summer; residential customers have 2 blocks in winter, 3 in summer.
(f) Declining block for commercial, uniform for wholesale.

rate schedule could be used to alleviate the poor load factor caused by summer residential irrigation. The AWWA cautions, however, that increasing block rates can be considered cost-of-service related only under special circumstances.

Many proponents of marginal-cost pricing also advocate seasonal pricing for conservation purposes because it ties prices to peak periods of use. Seasonal pricing can accomplish several goals:[44]

- *Cost recovery.* Higher rates during the summer season are considered to reflect a more equitable recovery of the cost of providing water service from those who use more water than average during the summer season.
- *Peak demand reduction.* Higher summer prices are intended to reduce peak daily and peak hourly demands, thus postponing or eliminating new capacity construction.
- *Extend available water supplies.* Where the supply is limited, or the development of additional sources is more expensive than available at present, the seasonal rate is considered a mechanism to postpone or eliminate the need for a major expansion of the system.
- *Conservation.* Higher summer prices are thought to encourage conservation and better utilization of the water supply and as a means of conserving natural resources, energy, and chemicals.

For a utility to adopt seasonal pricing, there must be substantial variation between peak and off-peak periods, installed capacity requirements must be determined primarily by peak demand, peak demand must occur consistently during the same season of each year, and the utility must be able to estimate the different costs associated with meeting peak and off-peak demand.[45] Russell provides guidelines for utilities contemplating the use of seasonal rates:[46]

- Detailed planning, complete and adequate information programs for customers, and careful administrative and computer procedures are essential for a successful program.

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[44] Russell, "Seasonal and Time of Day Pricing," in American Water Works Association, *Water Rates: An Equitability Challenge*, 92.
[45] Mann and Schlenger, "Marginal Cost and Seasonal Pricing," 7.
[46] Russell, "Seasonal and Time of Day Pricing," in American Water Works Association, *Water Rates: An Equitability Challenge*, 96.

- Any seasonal rate introduced should be relatively modest in price as compared with winter rates at the outset, with later adjustments to increase the differential.
- The summer excess charge method appears to be the superior method for matching revenues with costs and discouraging maximum summer demands.
- Any type of summer seasonal rate can cause more variations in revenue than a uniform annual rate.
- A seasonal rate may not be appropriate for all water systems. Where annual supplies are more than adequate and the system capacity is adequate or possibly excessive, a seasonal rate may discourage water sales and thus increase the cost of water for the remaining sales, without any substantial benefit to the water system except to possibly better recover costs from summer peaking customers.

Some analysts prefer the excess-charge method for seasonal pricing, even though the summer/winter form may be easier to administer and easier for customers to understand, because it is more effective for purposes of cost recovery and conservation.[47] However, determining excess use is difficult and may be perceived as arbitrary or inequitable.

A variation on the seasonal rate structure not mentioned in the AWWA collection of rate schedules is the indoor/outdoor rate schedule.[48] This approach is tailored to household consumption levels. It is designed to address the problem of inequity occurring when large households with desert landscaping pay more for water than small households with inefficient landscaping, even though the latter is contributing "more than its fair share" to the summer peak. Rates for indoor and outdoor use can be charged by installing two meters in each household. This not only would be inefficient and costly, it could also be bypassed by the homeowner who runs a garden hose from the kitchen sink.

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[47] Ibid.

[48] Gary C. Woodard, "A Summary of Research on Municipal Water Demand and Conservation Methodologies," in Arizona Corporation Commission, *Water Pricing and Water Demand*, 43-47.

There is a methodological solution to this problem. Household consumption during the off-peak season can be used to estimate basic indoor usage during the year. Amounts in excess of this level are billed at the outdoor water rate. Most water suppliers have the data necessary to make this calculation and may use it for bill estimation purposes at present. While the method is slightly inferior to indoor/outdoor meters, it is probably more equitable among households than simple seasonal rates or excess use charges. One potential inequity is that treatment costs associated with safe drinking water standards should generally be assigned to indoor water use or, more specifically, human consumption. However, there are significant economies of scale for water treatment and without a redundant distribution system the differentiation of costs on an indoor/outdoor basis is largely irrelevant.

In addition to these rate structures, some analysts have suggested the use of tax incentives through the form of credits or deductions for implementing conservation practices to promote voluntary conservation.[49] This method should also reduce peak use and average use. A precedent for this policy, of course, is the provision of tax credits for energy conservation. Edward F. Renshaw has suggested that, "A system of special credits for households and businesses that do more than their share to alleviate a temporary water shortage would seem equally fair and especially desirable from the point of view of promoting economic efficiency."[50]

Despite many methodological alternatives, rate design tends to be as much art as science, leaving a great deal of discretion to regulators. In his critique of lifeline rates, John F. Guastella concludes that rate design involves a considerable degree of "informed judgment" and that:

> Specific rate structures have and will continue to incorporate features relating to particular characteristics and objectives. So long as basic cost principles are not significantly compromised, there can be room for "policy" adjustments to effect gradual trends toward such goals as conservation, fuller recognition of economics [sic] of scale and even minimizing impact on low use customers.[51]

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[49] American Water Works Association, *Before the Well Runs Dry*, 63.

[50] Renshaw, "Conserving Water Through Pricing," 5.

[51] Guastella, "Lifeline and Social Policy Pricing," in American Water Works Association, *Water Rates: An Equitability Challenge*, 87.

For publicly owned water utilities, it may be simpler to incorporate policy goals into the ratemaking process. For investor-owned water utilities under the jurisdiction of the state public utility commissions, these goals must be reconciled with traditional principles of regulation. The inclination of the commissions to promote wise use or other policies may depend on legislative mandates, precedents in other utility areas, and whether outcomes are considered consistent with the public interest and other regulatory objectives.

Two Cities Compared

Some cities, while supporting the goal of conservation generally, contrast sharply over the issue of conservation rates. Tucson, Arizona and Denver, Colorado provide a useful comparison.

According to Gary C. Woodard, "Tucson is an example of a metropolitan area that has exhausted all inexpensive additions to its water supply."[52] Although its conservation efforts have been wide ranging, most analysts have focused on changes in the city's rates as its most significant conservation effort. Before a water delivery crisis in 1974, Tucson had flat or declining block rates. Since that time, several modifications have been made to encourage conservation and they have been largely successful.

As of 1986, Tucson's water department implemented a water rate schedule using both increasing blocks and seasonal differentials, as reported in table 8-7.[53] A comprehensive analysis of the Tucson case by Richard W. Cuthbert reveals that single-family residents are sensitive to changes in inflation-adjusted water rates. While it is not certain that single-family ratepayers were aware of the increasing block rate structure, water

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[52] Woodard, "A Summary of Research on Municipal Water Demand and Conservation Methodologies," in Arizona Corporation Commission, *Water Pricing and Water Demand*, 32.

[53] Richard W. Cuthbert, "Effectiveness of Conservation-Oriented Water Rates in Tucson," *American Water Works Association Journal* 81, no. 3 (March 1989): 65-73.

TABLE 8-7

SEASONAL INVERTED WATER RATES FOR TUCSO ARIZONA

Charges	Winter	Summer
April 1977		
Monthly service charge	$1.40	$1.40
Commodity charge		
First 1,000 cubic feet/month	0.55	0.55
Next 1,000 cubic feet/month	0.55	0.66
Next 3,000 cubic feet/month	0.55	0.77
> 5,000 cubic feet/month	0.55	0.88
May 1986		
Monthly service charge	$3.70	$3.70
Commodity charge *		
First 500 cubic feet/month	0.86	0.86
Next 500 cubic feet/month	0.97	0.97
Next 1,000 cubic feet/month	1.15	1.33
Next 1,000 cubic feet/month	1.31	1.64
Next 2,000 cubic feet/month	1.45	1.85
> 5,000 cubic feet/month	1.61	2.08

Source: Reported in Richard W. Cuthbert, "Effectiveness of Conservation-Oriented Water Rates in Tucson," *American Water Works Association Journal*, Vol. 81, No. 3 (March 1989): 67 and 69.

* Excluding Central Arizona Project surcharge of $0.02/100 cubic feet.

consumption did decline after its implementation. Finally, reduced consumption, especially among high-use customers, led to an overall reduction in consumption for the single-family residential customer class.

One shortcoming of Tucson's conservation program may be in the area of consumer awareness. Woodard observes that consumers are generally unaware of increasing block and seasonal rates designed to encourage conservation.[54] According to Mark Day:

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[54] Woodard, "A Summary of Research on Municipal Water Demand and Conservation Methodologies," in Arizona Corporation Commission, *Water Pricing and Water Demand*, 38.

> Consumer acceptance of innovative pricing seems to be very good because people do not complain, but, at the same time, very poor because 80 percent of the customers were unaware that innovative pricing measures existed after 5 years of living in Tucson. Innovative rate structures which are too subtle or under-publicized to be well recognized seem pointless, except as they affect average price.[55]

Denver, on the other hand, has explicitly rejected the idea of using water utility rates for conservation purposes despite a recognition of their potential impact. The Denver City Charter provides that water rates "shall be as low as good service permits" and that "[no] special rate of discount shall be allowed."[56] The city's water department reasons that rates will affect discretionary uses, which vary from household to household and across customer classes, but have no effect on nondiscretionary uses. Moreover, the department concludes that:

> It is not the purpose of a conservation program, nor is it necessary for water conservation, to charge more for water service within the City and county of Denver than the costs of providing this service, or to prevent the aggregate rates from being "as low as good service will permit. . . . The rate analysis study, not the water conservation plan, is the appropriate vehicle to integrate conservation objectives with the many other issues appropriate to utility ratemaking.[57]

Robert E. Weidemann, of the Denver Board of Water Commissioners, has argued that conservation by price reflects an artificial rate structure that is "confiscatory" and has the objective of "pricing water so that customers cannot afford to use it."[58] Although he acknowledges that increasing block rates may be justified during a short-term water crisis, he contends that the renewability of Denver's water resources make conservation rates unsuitable. Finally, Weidemann argues that water utilities should engage in aggressive and extensive education programs to motivate their customers to conserve, but if the customers do not choose to do so, it is the water utility's responsibility to increase supplies.

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[55] Day, "A Discussion of Empirical Evidence," in Arizona Corporation Commission, *Water Pricing and Water Demand*, 38.

[56] Denver Water Department, *Water Conservation Plan of the Denver Water Department* (Denver, CO: Denver Water Department, 1986), 22.

[57] Ibid.

[58] Robert E. Weidemann, "Inverted Rate and Conservation Pricing," in American Water Works Association, *Water Rates: An Equitability Challenge*, 78-79.

Rather than adjust rates to induce conservation, Denver emphasizes other conservation strategies. For example, city officials are zealous about making xeriscape, the use of water-efficient landscaping, the central focus of the community's conservation efforts.

Emerging Regulatory Issues

As noted above, ratemaking is but one of the many regulatory functions that public utility commissions perform. They also make determinations affecting the future water supplies and the management of existing supplies. A commission, for example, might require a water utility to obtain a certificate of convenience and necessity for a new storage or treatment facility, get approvals for financing, or submit a long-term planning document. Three issue areas on the horizon that have emerging importance for regulatory commissions are system adequacy, water markets, and least-cost planning.

System Adequacy

Droughts and other forms of water shortage have called into question the adequacy of many water supply systems. According to Sandra Postel of the Worldwatch Institute, large water projects are increasingly unattractive and difficult to implement because of high costs, tight budgets, and environmental risks.[59] Yet water managers and public officials continue to exhibit a predisposition toward increasing supplies rather than reducing demand, the result of which "can only lead to worsening water deficits and economic disruption."[60]

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[59] Sandra Postel, "Increasing Water Efficiency," in Lester R. Brown, et al., *State of the World 1986* (New York: W. W. Norton and Co., 1986), 61.
[60] Ibid.

Indeed, there appear to be at least two competing philosophies in water supply.[61] The more traditional view, sometimes associated with the engineering discipline, argues for maintaining a continuous level of reliable supply (or safe yield), with little regard to cost. The other view, sometimes associated with economics or policy analysis, emphasizes risk management and presumes that water customers will tolerate and adjust to occasional shortages (such as those occurring with a drought) and invest in less costly water-saving measures rather than continuous supply.

Because the easily developed water sources have already been developed, the cost of new supplies is substantial. The per-unit cost of water, for both development and treatment, could escalate at a pace rivaling that for electricity in the 1970s. Some cost projections for the Federal Central Valley Project and the State Water Project are presented in table 8-8. The

TABLE 8-8

PROJECTED WATER PRICES FOR CALIFORNIA

Service Area	Price per acre-foot (1980 dollars)			
	1980	1990	2000	2010
Federal Central Valley Project				
Sacramento Valley	$3.50	$3.50	$9.00	$12.00
San Joaquin Valley (east side and Delta-Mendota Canal)	3.50	3.50	12.00	16.00
San Joaquin Valley (San Luis)	10.00	10.00	17.00	24.00
State Water Project				
South Bay Aqueduct	44.00	120.00	120.00	120.00
San Joaquin Valley (Kern County Water Agency)	29.00	80.00	80.00	80.00
Southern California (Metropolitan District)	123.00	275.00	275.00	245.00

Source: California Department of Water Resources as reported in Zach Willey, *Economic Development and Environmental Quality in California's Water System* (Berkeley, CA: University of California, Institute of Governmental Studies, 1985), 15.

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[61] Prasifka, *Current Trends in Water-Supply Planning*, 22.

prices that result from these costs may be so high that reductions in demand attributable to elasticity effects could actually negate the need for the proposed new supplies. Several analysts contend that more efficient supply management is preferable to large-scale water projects.[62]

As mentioned previously, an important area of water supply management is reducing water losses. Leak detection and repair, for example, may be one of the most cost-effective ways of increasing available water and offsetting the need for new capacity. An adequate leak detection and repair program should be a prerequisite of any plan for developing new supplies. In fact, what utilities do about leaks may be a good indicator of their overall management prudence. For some utilities, pressure reduction and resource management may be appropriate strategies as well.[63] Better supply management may actually reduce the frequency of water shortages.

Furthermore, a water shortage (such as a drought) does not necessarily justify additions to supply even if water sources are available for development. One study in particular warns against the use of drought as a rationale for building essentially excess capacity for the water industry:

> [S]ystem shortages do not mean disaster, and perhaps if more effort were made to spell out beforehand the consequences of various "failure" levels, public acceptance could be won for more rational planning. In short, "drought" need not constitute, as it now does, a convenient natural clock for hiding past planning failures or garbing for public acclaim plans for building expensive monuments to the "right" to cheap water.[64]

Suppliers with excess capacity have less incentive to conserve because utilities want to recover their capital costs by expanding demand, not curtailing it. For utilities where supply and demand are in close proximity, however, managers and regulators may have to choose among supply management and demand management alternatives to deal with potential shortages. According to Renshaw, it may make more economic sense for some utilities to develop strategies for coping with the occasional drought rather than overbuild water system capacity:

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[62] John R. Schaeffer and Leonard A. Stevens, *Future Water: An Exciting Solution to America's Most Serious Resource Crisis* (New York: William Morrow and Company, 1983), 15.

[63] See chapter 7.

[64] Clifford S. Russell, David G. Arey, Robert W. Kates, *Drought and Water Supply: Implications of the Massachusetts Experience in Municipal Planning* (Baltimore, MD: Johns Hopkins Press, 1970), 81-83.

> From an economic point of view, the objective is to balance economic losses from occasional water shortages against the higher capital and maintenance expenses for drilling extra wells or building larger storage reservoirs that are not always needed. . . . If it is not recognized that there is an economic tradeoff between water supply costs on one hand and the minor inconvenience of having to reduce consumption occasionally in time of drought, the cost of water could be raised to uncompetitive levels, creating an economic environment that is more detrimental to business expansion than an occasional lack of an assured water supply.[65]

Some analysts contend that both market incentives and least-cost criteria will provide water suppliers with incentives to invest in alternative or nonstructural water supplies.[66] These include groundwater storage, wastewater reclamation, and demand-reducing improvements that promote efficient use, as compared with structural projects such as dams or diversions.

Water Markets

Some resource economists have turned their attention to the potential of water markets for allocating water and water rights more efficiently and creating surplus resources available for alternative uses.[67] The emergence of water markets can be traced to several specific factors, as identified by Steven J. Shupe.[68] One is the finite quantity of supplies, particularly in the West. A second is the limited amount of federal money available for building new water supplies. Third is the relative cost advantage of buying irrigation water as compared to building new supply sources. Fourth is the environmental impact assessment process, which can be used to postpone or cancel large-scale water resource projects.

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[65] Renshaw, "Conserving Water Through Pricing," 4.

[66] Zach Willey, *Economic Development and Environmental Quality in California's Water System* (Berkeley, CA: University of California, Institute of Governmental Studies, 1985), 2.

[67] Gary D. Weatherford, ed., *Water and Agriculture in the Western U.S.: Conservation, Reallocation, and Markets* (Boulder, CO: Westview Press, 1982); Bonnie Colby Saliba and David B. Bush, *Water Markets in Theory and Practice* (Boulder, CO: Westview Press, 1987); and Larry Morandi, *Reallocating Western Water: Equity, Efficiency, and the Role of Legislation* (Denver, CO: National Conference of State Legislatures, 1988).

[68] "Water Marketing: An Overview," (an interview with Steven J. Schupe), *American Water Works Association Journal* 80, no. 3, (March 1988): 18-26.

Some blame water shortages and the water crisis on the misallocation of water resources caused by artificially low prices and the untapped potential of water markets:

> By understanding the potential for market allocation of water resources and the potential for government failure in the allocation of those resources, the potential exists for resolving our institutional water crisis. With more reliance on markets, it is possible to have less environmental destruction of water resources, more economic growth, and more individual freedom. If a coalition can be formed with an understanding of these potential gains, there is hope for averting the water crisis.[69]

The implementation of water markets depends on numerous considerations, some of which may be outside the control of the water supplier. Assuming available supplies and physical interconnections, fostering the use of water markets may depend largely on the configuration of water rights and whether the institutional context presents barriers or provides incentives to transferring those rights.[70]

Water markets provide an "institutional setting in which the right to use water is bought, sold, or traded among consenting parties."[71] Put another way, water markets institutionalize the competition for water among users. They may also provide a way for some large users to bypass the public supplier altogether. More than simply buying and selling water rights, water markets encompass such things as:[72]

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[69] Terry L. Anderson, *Water Crisis: Ending the Policy Drought* (Washington, DC: CATO Institute, 1983), 121.

[70] See Weatherford, ed., *Water and Agriculture in the Western U.S.*; Saliba and Bush, *Water Markets in Theory and Practice;* and Morandi, *Reallocating Western Water*.

[71] Bonnie Colby Saliba, et al., *Water Marketing in the Southwest--Can Market Prices Be Used to Evaluate Water Supply Augmentation Projects?* (Fort Collins, CO: Forest Service, U.S. Department of Agriculture, 1987), 2.

- Financing water conservation practices to make surplus water available for transfer to other uses.
- Water banking whereby excess surface water in one year is stored in aquifers and managed conjunctively with groundwater through water exchanges in future years.
- Dry-year options in which farmers forego water use during droughts and lease water to municipalities for cash payments to compensate for crop losses.
- Selling excess surface water storage space to facilitate the release of impounded water to meet instream flow needs.

The use of water markets requires that water rights be well defined and that the use of the water be severable from adjacent land, or that the land can be acquired along with water rights. Water markets may require water wheeling through the transportation facilities of a third-party water supplier, which may involve regulatory approvals. Above all, the use of water markets requires the "relaxation of legal restrictions on transfer; the ascendancy of pricing as a mechanism for allocating water; and a rise in the conservation and efficient use of water."[73]

So far, markets for water are not well defined or comprehensive.[74] There may be limits to the promulgation of water markets. At least three factors have the potential to temper their success.[75] One is imperfect competition caused by physical, economic, or institutional barriers. Imperfect competition sometimes leads to government intervention, including regulation. Another problem is the inequity caused by redistributing water rights--which are essentially assets--away from rural economies. A third is the persistent confrontation over ownership of water rights in the first place, particularly when Indian tribes are involved.

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[72] *Water Market Update 2* (January 1988) as reported in Morandi, *Reallocating Western Water*, 3-4.

[73] Gary D. Weatherford, "Water Allocation: Market Proficiency and Conflicting Social Values, in Weatherford, ed., *Water and Agriculture in the Western U.S.*, 193.

[74] N. Wollman and G. E. Bonem, *The Outlook for Water-Quality, Quantity and National Growth* (Baltimore, MD: Resources for the Future and The Johns Hopkins Press, 1971), as cited by Warren Viessman, Jr. and Christine DeMoncada, *State and National Water Use Trends to the Year 2000* (Washington, DC: Congressional Research Service, Library of Congress, April 1980), 273.

[75] F. Lee Brown and Charles T. DuMars, "Water Rights and Market Transfers," in Engelbert and Scheuring, eds., *Water Scarcity*, 408-36.

A high degree of market imperfection actually may lead to government regulation of water markets or, at least, modifications in how they operate.[76] As a former director of a state natural resource agency remarked, "unless you intervene in the process, water tends to flow toward money, and that creates a lot of social and economic problems you have to deal with."[77] Increasing attention will be paid not only to the legal ramifications of water transfers but their implications for social values.[78] To the extent that public water suppliers are able to utilize water markets, these issues may require further consideration.

Least-Cost Planning

Least-cost water-supply planning may emerge as a significant regulatory tool, as it has in the energy utility area. A basic premise of least-cost planning is that all options for meeting future demand should be compared according to the least-cost standard. Water utility executives are acutely aware of the growing interest in least-cost planning:

> Although water utilities have considered the least-cost approach in their planning process, they have not historically taken what commissions define as a least-cost planning approach to determining whether or not to build additional facilities. The focus of water utility executives has been on engineering considerations--i.e.: additional plant and more source of supply with adequate reserve to ensure maximum day demands can be met. . . . However, in the environment in which we operate today, there are those who are challenging the engineering approach as not being

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[76] Ibid.

[77] Quoted in James L. Wescoat, Jr., *Integrated Water Development* (Chicago: Department of Geography, University of Chicago, 1984), 183.

[78] Philip C. Metzker, "Protecting Social Values in Western Water Transfers," *American Water Works Association Journal* 80, no. 3 (March 1988): 58-65.

> totally prudent, suggesting that demand-side options ought to be considered as part of the planning process.[79]

A shift in focus to least-cost allows for the comparison of traditional structural options with nonstructural supply alternatives, particularly water conservation. According to a study by the Congressional Research Service, "A consistent theme in much of the professional literature is on demand management rather than supply expansion."[80] Many analysts believe that the prudence of water conservation can and should be evaluated when considering traditional resource development alternatives. This view requires that conservation receive "resource status," meaning that it is assessed in the same economic terms and with the same types of analyses as other water resources.[81]

Several water conservation alternatives were reviewed in chapter 7 of this report. These included supply management measures that may be implemented by water suppliers as well as demand management measures that may be implemented by either suppliers or users. In a least-cost planning framework, many of these alternatives can be compared with traditional supply options because they reduce the need for water withdrawals.

For example, one of the most promising strategies for demand management is wastewater reuse for irrigation. Table 8-9 reports a 1967 cost comparison of reclaimed sewage effluent and water supply alternatives. In all but one case, reuse was the favored alternative; the exception may have been an incomplete cost calculation. In response to the growing interest in this application, a 1987 Texas statute directed the state Water Commission to develop rules for reuse of gray water (including household wastewater) for on-site irrigation and other agricultural, domestic, and industrial applications.[82] Other state commissions have also expressed an interest in reuse because it offsets the need for withdrawals.

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[79] Edward W. Limbach, "Least Cost Planning for Water Utilities: A Balancing Act," presented at the Mid-America Regulatory Conference in Chicago, Illinois (June 1989), 3-4.

[80] John L. Moore, et al., *The Nation's Water Supply: An Overview of Conditions and Prospects* (Washington, DC: Congressional Research Service, Library of Congress, 1986), iv.

[81] Olsen and Highstreet, "Socioeconomic Factors," 68.

[82] American Water Works Association, *Mainstream* 33, no. 1 (January 1989): 1 and 10.

TABLE 8-9

COST COMPARISON OF RECLAIMED SEWAGE EFFLUENT AND WATER SUPPLY ALTERNATIVES

Location	Type of Use	Cost of Reclaimed Effluent ($/ac.ft.)	Cost of Alternative Water Supply ($/ac.ft.)
Pomona, Ca.	Irrigation	$6.00-7.60	$20.00
San Bernadino, Ca.	Irrigation	0.31	10.00
San Francisco, Ca.	Parks, lakes	23.00	70.00
Taft, Ca.	Irrigation	6.00	None available
Talbert, Ca.	Irrigation	6.00	Unsatisfactory
Abilene, Texas	Irrigation	no cost	80.00
Kingsville, Texas	Irrigation	no cost	65.00
San Antonio, Texas	Irrigation	no cost	25.00
Grand Canyon, Arizona	Lawn irrigation	120.00	550.00
Santa Fe, New Mexico	Golf course	49.00	75.00
Las Vegas, Nevada	Golf course	27.00	30.00
Big Springs, Texas	Oil refinery	16.00	57.00
Baltimore, Maryland	Steel plant	11.00	44.00
Amarillo, Texas	Oil refinery	14.00	45.00
Los Alamos, Texas	Power plant cooling	24.00	92.00
Los Angeles, Ca.	Groundwater recharge	18.00	42.00
Whittier Narrows, Ca.	Spreading	16.85	14.00*

Source: R.J. Frankel (1967) as reported in Duane D. Baumann, John J. Boland, John H. Sims, Bonnie Kranzer, and Philip H. Carver, *Planning and Evaluating Water Conservation Measures* (Chicago, IL: American Public Works Association, 1981), 21.

* This is the Metropolitan Water District of Southern California rate for groundwater replenishment. It does not represent the total cost of imported water. Future additions from the Feather River are estimated to cost from $50 to $100 per acre-foot.

As illustrated in table 8-10, there also is dramatic evidence of the comparative cost advantages found in demand reduction methods. For each of the San Francisco Bay area utilities compared, the demand reduction alternative produced a far greater yield and was less expensive on a per-unit basis. In fact, the cost of augmenting supplies was about twice as much as reducing demand through conservation, even when an estimate of the cost of the water shortage to consumers was included.

A third least-cost analysis is presented in table 8-11. It compares nonstructural strategies, including reuse, to structural strategies for increasing water supplies in southern California. The least-cost alternative is to use conservation and transfers from irrigation to produce a yield of 370,200 cubic meters at a marginal cost of $545 per thousand cubic meters. Developing groundwater basins in this example can be accomplished at a lower cost than wastewater reuse. Reservoir construction does not compare favorably in this least-cost assessment.

According to Darryll Olsen and Allan L. Highstreet, conservation has some distinct advantages over other resources but also some potential drawbacks:

> From an engineering perspective, water conservation is perhaps the most flexible resource available because there is not a lengthy period of siting and licensing for the design and construction of conservation. It can be quickly brought on-line, and conservation can be acquired in varying increments. However, to be effective, conservation cannot be turned on and off, and programs must be continuously and consistently applied.[83]

Thus, in making least-cost evaluations, all facets of supply management and demand management should be taken into account.

Commission Policies on the Wise Use of Water

Many public utility commissions have only recently begun formally to apply the wise-use theme to their jurisdictional water utilities. A recent survey of eleven state public utility commissions in the southeastern United States found that none had implemented formal conservation programs for their jurisdictional water utilities.[84] Only Tennessee reported some use of increasing block rates, while several reported use of declining block rates. According to Florida Commissioner John T. Herndon, who conducted the survey, the "real tragedy" of the survey findings is that regulators are generally

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[83] Olsen and Highstreet, "Socioeconomic Factors," 68.

[84] The Honorable John T. Herndon, "Water Conservation," *Water* 30, no. 3 (Fall 1989): 22-23.

TABLE 8-10

COMPARISON OF DEMAND REDUCTION WITH SUPPLY AUGMENTATION: FOUR CALIFORNIA CASES

Water District and Policy Type	Costs in Dollars		Estimated Cost of Shortage to Consumers	Yield in acre-feet(a)	Unit Cost in $ per acre-ft
	Capital	Operating			
East Bay Municipal Utility District					
demand reduction	$ 0	$ 633,780	$ 8,510,000	102,408	$ 89
supply augmentation(b)	4,250,000	1,400,000	0	36,000	156
San Francisco Water District					
demand reduction	0	419,000	1,510,000	31,455	61
supply augmentation(c)	0	590,000	0	5,137	115
Contra Costa County Water District					
demand reduction	0	73,000	990,000	7,875	135
supply augmentation(d)	325,000	18,150	0	1,100(e)	312
Marin Municipal Water District					
demand reduction	0	632,500	5,500,000	20,062	308
supply augmentation(f)	1,200,000	1,600,000	0	3,988	708

Source: Mark Hoffman, Robert Glickstein, and Stuart Liroff, "Urban Drought in the San Francisco Bay Area: A Study of Institutional and Social Resiliency," in American Water Works Association, *Water Conservation Strategies* (Denver, CO: American Water Works Association, 1980), 82.

(a) Yields are based on the reduction of consumption between 1976 and 1977.
(b) Middle River pumping project.
(c) Water purchases from SWP, Presidio, and some well testing.
(d) Five new wells.
(e) Estimated annual yield after February 1978.
(f) Construction and operation of pipeline; water purchases.

TABLE 8-11

COST COMPARISON OF CONSERVATION AND WATER SUPPLY ALTERNATIVES FOR SOUTHERN CALIFORNIA

Representative Alternative	Annual Yield in Thousand Cubic Meters	Marginal Cost in Dollars per Thousand Cubic Meters
Conserve/Transfer Irrigation Water I	370,200	$ 545
Develop Groundwater Basins	236,900	575
Reclaim and Reuse Wastewater	299,500	648
Conserve/Transfer Irrigation Water II*	493,600	665
Build Newville Reservoir/ Increase Diversions of Northern Water	271,500	750
Build Los Vaqueros Reservoir/ Increase Diversions of Northern Water	327,000	943

Source: Robert Stavins, "Trading Conservation Investments for Water," (Environmental Defense Fund, Berkeley, California, March 1983) as adapted by Sandra Postel, "Increasing Water Efficiency," in Lester R. Brown, et al., *State of the World 1986* (New York: W. W. Norton and Co., 1986), 59.

* Includes lining a major canal in addition to the measures of the first conservation alternative.

unaware of whether the states in which they serve have a conservation program or which state agency is responsible for its administration.

Herndon concluded that utility regulators have a duty to encourage the productive and efficient use of water resources through activities that include:[85]

- Participating in gubernatorial task forces on water conservation, such as that established in Kentucky.
- Developing PUC programs and policies that encourage conservation; that is, discounts by companies, incentives, etc.
- Carefully examining the inverted rate structure.

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[85] Ibid., 23.

- Working toward the adoption of reuse policies, new plumbing codes, and so on, in the states.
- Pursuing leak detection programs.

Still, several commissions have taken initiatives in supply planning and conservation. The Kentucky Public Service Commission, for example, recently ordered the Kentucky-American Water Company to produce a comprehensive strategic planning and resource acquisition study that included:[86]

- An evaluation of conservation and curtailment programs during periods of peak water demand;
- An evaluation of the impacts of the company's declining block rate structure on water consumption;
- An evaluation of alternative rate designs and their effect on the efficient use of water;
- Development of a program to encourage the construction industry to install more water-efficient plumbing fixtures;
- Development of an aggressive public education campaign to cultivate a conservation ethic among the company's customers;
- A summary of conservation programs initiated by other water utilities that might be relevant to the company's efforts;
- A summary of the anticipated role of the company's consumers advisory council in encouraging the efficient use of water.

In late 1988, the Rhode Island Public Utilities Commission issued an order allowing the Providence Water Supply Board to raise its rates to make improvements to the utility's water plant and distribution systems.[87] While recognizing that its authority over water resource planning is somewhat limited, the Commission reiterated its belief that the "encouragement of conservation and prudent use of. . . . facilities by utilities must remain the central focus of Commission policies and directives."[88] The utility was ordered to undertake "programmatic conservation efforts to reduce water usage," possibly including public information, water audits, technical assistance to water users, residential and industrial retrofit programs, combined billing with another utility, support for plumbing code changes, evaluation of pressure reduction, and leak detection and repair. Other measures include the phasing out of declining block rates, developing and implementing a comprehensive conservation program, participating in a joint conservation program with the Narragansett Bay Commission, conducting a demand forecast study, and developing an emergency response plan.

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[86] American Water Works Service Company, Inc., *Kentucky-American Water Company Least Cost/Comprehensive Planning Study Technical Appendix* (Haddon Heights, NJ: American Water Works Service Company, Inc., 1986), A-1.2.

[87] National Association of Regulatory Utility Commissioners, *Bulletin*, no. 49-1988 (December 5, 1988): 8-9.

Also in late 1988, the New York Public Service Commission began hearings to consider how recent changes in water resource protection and conservation will affect how regulated water utility customers use and pay for water.[89] As part of these hearings, the Commission is requiring its eighteen largest jurisdictional water utilities to submit information on future water supplies and new water sources, measures being undertaken to reduce water leakages and conserve water, and plans for financing any improvements to be made for environmental or conservation purposes.

In 1989, the Pennsylvania Public Utilities Commission adopted a policy requiring the Commission to take into account the water conservation efforts of jurisdictional water utilities when setting rates.[90] In addition to distributing information to their customers about efficient water use and water-saving plumbing fixtures, the state's 334 regulated water companies also are expected to make conservation a priority when managing their own water resources. For example, unaccounted-for water should not exceed 20 percent, leak detection surveys should be performed, customers and supply sources alike should be metered, and conservation contingency plans should be developed and implemented.

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[88] *Re Providence Water Supply Board, Docket No. 1900* (November 14, 1988).

[89] National Association of Regulatory Utility Commissioners, *Bulletin*, no. 50-1988 (December 12, 1988): 25.

[90] National Association of Regulatory Utility Commissioners, *Bulletin*, no. 11-1989 (March 13, 1988): 20.

The Connecticut Department of Public Utility Control recently approved a rate increase for Bridgeport Hydraulic Company that was about 45 percent of the utility's requested increase, in part because the company had failed to strategically plan its construction program to meet water quantity and quality needs.[91] The Department also ordered the utility to identify and develop additional groundwater sources, consider purchasing some water from another supplier, and undertake a major water conservation initiative in consultation with local officials and other parties. Following an investigation of the adequacy of the conservation plans of all jurisdictional water utilities, the Department later issued a water conservation report providing information on steps that can be taken to encourage conservation and improve water resource planning, including rate structure modification.[92]

Integrated Resource Planning for Water Utilities

As general interest in the wise use of water expands, perhaps in response to water scarcity, regulatory policies are likely to follow. Public utility commissions may be in a unique position to advance *integrated* resource planning for jurisdictional water utilities. Integrated planning may be another vehicle for promoting the wise use of water. Although the term is sometimes used to refer to integrated supply and demand planning or least-cost planning, integration in water resource planning has the potential to be a more encompassing concept. Integration can occur on several planes:

> *Temporal*. Integration of short-term planning, including drought contingency plans, with long-term planning; integration of forecasts of water supply with forecasts of water demand; integration of crisis management with risk management.
>
> *Spatial*. Integration of planning needs for all the suppliers within a water resource region and across regions, with particular attention to the quantity and quality of the region's water resources and such issues as water rights.

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[91] National Association of Regulatory Utility Commissioners, *Bulletin*, no. 25-1989 (March 13, 1988): 4.

[92] National Association of Regulatory Utility Commissioners, *Bulletin*, no. 39-1989 (September 25, 1989): 10.

> *Interdisciplinary.* Integration of engineering, economic, legal, social, health, safety and other relevant perspectives in developing, implementing, and evaluating water resource plans; integration of supply management and planning with demand management and planning.
>
> *Institutional.* Integration of jurisdictional water utility planning with statewide water resource planning, including planning for nonjurisdictional water, wastewater, and energy utilities; integration of water resource planning with land-land-use and other resource planning efforts; integration of public policy alternatives in the areas of water supply and water demand.
>
> *Participatory.* Integration of the priorities of water suppliers with those of government officials, representatives of water users, and the public at large; integration of federal, state, and local water resource policymaking through mutual coordination and participation.

Not surprisingly, when water is in short supply, the question of adequate planning is likely to arise. While water suppliers cannot be held accountable for drought, they can be held accountable for being caught unprepared. With or without drought, water customers expect adequate and reliable service. They may also expect government officials to see to it that jurisdictional utilities are prepared to meet their service obligations. Thus, the burden of planning falls not only on water suppliers, but on their regulators as well. An integrated approach may prove to be most useful for meeting this challenge.

CHAPTER 9

FEDERALISM AND WATER POLICY

An illustration appearing in a publication of the Freshwater Foundation depicts the pluralistic nature of water supply policy with a rain cloud over a complex configuration of water pipes that connect social attitudes, environmental concerns, the setting of priorities, legal constraints, scarce funds, economic issues, diversion, technological considerations, politics, and special interests, in the midst of which are the federal government and the states.[1]

The pervasive role of governmental agencies in water resource policy is illustrated in table 9-1, which counts the number of governmental units making water resource policy in the state of Minnesota: more than three thousand governmental units in all.[2] Based on this compilation, it is no wonder that the entire area of water resource policymaking in the United States is fragmented and pluralistic, so much so that it may appear weak and ineffective.[3] The water supplier today may be accountable to so many governmental authorities that accountability itself is threatened.

Some observers link the expanded role of government in water policy, particularly at the federal level, to the nature of water politics:

> The politics of water invariably becomes more intense at the state and local level than at the federal level. At the local level, who benefits and who loses as a result of water policies becomes painfully obvious. What are essentially local political issues, however, are often fought out at the federal level. That is because the role of the federal government in water has become so pervasive. By shifting the

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[1] Freshwater Foundation, *Supplying the Demand: The Water Management Challenge* (1984), as reproduced in David W. Prasifka, *Current Trends in Water-Supply Planning* (New York: Van Nostrand Company, 1988).

[2] One of the few agencies not on the list is the Minnesota Public Utilities Commission, which has no jurisdictional water utilities. In forty-six states, however, public utility commissions would be counted among these agencies.

[3] Political scientists refer to this situation as hyperpluralism.

TABLE 9-1

WATER POLICY AND PLURALISM IN MINNESOTA

Type of Government Organization	Number
Federal executive agencies	8
Federal independent agencies	4
Executive Office of the President	1
Special federal boards and committees	unknown
Interstate associations and commissions	6
Intrastate commissions and boards	18
State agencies and boards	15
Lake conservation districts	2
Drainage and conservation districts	3
Lake improvement districts	3
Rural water user districts	5
Port authorities	5
Sanitary districts	7
Watershed districts	37
Farmers Home Administration county committees	63
Agricultural Stabilization and Conservation Service county committees	90
Soil and Water Conservation Districts	92
Counties	87
Municipalities	855
Townships	1,795
Total	3,098+

Source: Freshwater Foundation, *The Journal of Freshwater* (1983) as reported in Concern, Inc., *Drinking Water: A Community Action Guide* (Washington, DC: Concern, Inc., 1986), 16.

> arena for debate upwards, the local political process can avoid dealing with the unpleasant aspects of water (e.g. who pays) on its own turf.[4]

More than one analyst has pointed out that institutional forces often frustrate rather than facilitate policymaking in water supply management and regulation. Removing these barriers may be essential to improving public policy addressing water issues and meeting future demands.[5] Many critics also blame the institutional quagmire for the lack of a national water resource policy.

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[4] Charles H. W. Foster and Peter P. Rogers, *Federal Water Policy: Toward An Agenda for Action* (Cambridge, MA: Energy and Environmental Policy Center, John F. Kennedy School of Government, Harvard University, 1988), 7.

On the other hand, Charles H. W. Foster and Peter P. Rogers note that while *national water policy* has a nice ring to it, in reality it is only "the sum total of a number of individual federal, state and regional policies."[6] Thus the term *federal water policy* is often preferable. This chapter examines the pluralistic context of water supply planning and management focusing on the various governmental units in the federal system--aside from the state public utility commissions--that make policy in the areas of water supply, drought, and conservation.

Federal Water Policy

A pluralistic view of American government may be particularly applicable to federal water policy, which is--at least with respect to water resources--expansive. Drawing principally on its constitutional authority to regulate interstate commerce, of which navigable waters are an integral part, Congress has enacted numerous statutes affecting the nation's water resources. Many of these are reported in table 9-2. No fewer than twelve congressional committees and twenty-three subcommittees affect federal policy toward water resources.[7]

Water policy at the federal level is essentially a collection of authorizations, appropriations, and the administrative policies and programs of the bureaucracy. The regulatory impact of these policies is massive. Since the turn of the century, more than twenty commissions or committees have studied the nation's water resource policies and made recommendations for improvement to the president or Congress or both.[8]

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[5] See for example, Sandra Postel, "Increasing Water Efficiency," in Lester R. Brown, et al., *State of the World 1986* (New York: W. W. Norton and Co., 1986), 41.

[6] Foster and Rogers, *Federal Water Policy*, 4.

[7] Lawrence Mosher, "Localities Begin to Challenge Government's Water Policy Vacuum," *National Journal* (January 28, 1984): 167.

[8] Peter E. Black, *Conservation of Water and Related Land Resources* (New York: Praeger Publishers, 1982), 92-93.

TABLE 9-2

CHRONOLOGY OF FEDERAL LEGISLATION SUBSTANTIALLY AFFECTING WATER RESOURCE POLICY

- The Refuse Act of 1899
- Reclamation Act of 1902
- Oil Pollution Act of 1924
- Soil Conservation Act of 1935
- Flood Control Act of 1944, 1962
- Water Pollution Control Act of 1948, 1956, 1972, 1977, and 1981
- Water Supply Act of 1958
- Watershed Protection and Flood Prevention Act of 1964
- Water Resources Research Act of 1964.
- Water Resources Planning Act of 1965 and 1974
- Water Quality Act of 1965 and 1987
- Clean Rivers Restoration Act of 1966
- National Environmental Policy Act of 1969
- Environmental Quality Act of 1970
- Clean Water Act of 1977
- Coastal Zone Management Act of 1972
- Federal Insecticide, Fungicide and Rodenticide Act of 1972
- Marine Mammal Protection Act of 1972
- Marine Protection, Research and Sanctuaries Act of 1972
- Weather Modification Reporting Act of 1972
- Offshore Shrimp Fisheries Act of 1973
- Safe Drinking Water Act of 1974, 1977, and 1986
- Fishery Conservation and Management Act of 1976
- Resource Conservation and Recovery Act of 1976
- Toxic Substances Control Act of 1976
- Water Resources Development Act of 1976
- Soil and Water Resources Conservation Act of 1977
- Surface Mining Control and Reclamation Act of 1977
- Agricultural Credit Act of 1978
- Uranium Mill Tailings Radiation and Control Act of 1978
- Comprehensive Environmental Response, Compensation and Liability Act of 1980 (Superfund)
- Pacific Northwest Electric Power Planning and Conservation Act of 1980
- Food Security Act of 1985
- Superfund Amendments and Reauthorization Act of 1986
- Water Resources Development Act of 1986
- Water Quality Act of 1987

Source: Authors' construct.

Recently proposed legislation identifies many of the federal agencies that participate in water resource planning, development, and management, as reported in table 9-3. As indicated in table 9-4, at least ten federal agencies collect water data for the nation. Within the Department of Agriculture alone, eight separate offices are involved in soil and water conservation. Within the U.S. Geological Survey, twenty-one separate water programs exist. Appendix C to this report provides a summary of the programs of the many agencies involved in federal water policy as well as the fifteen interstate water agencies.

TABLE 9-3

FEDERAL OFFICES SUBSTANTIALLY AFFECTING WATER RESOURCE POLICY

Legislative Offices

- United States Congress
  - Congressional Committees
  - General Accounting Office
  - Library of Congress
  - Office of Technology Assessment

Executive Offices

- Executive Office of the President
  - Council on Environmental Quality
  - Office of Science and Technology Policy
- Department of Agriculture
  - Agricultural Research Service
  - Agricultural Stabilization and Conservation Service
  - Cooperative State Research Service
  - Economic Research Service
  - Extension Service
  - Farmers Home Administration (FmHA)
  - Forest Service
  - Soil Conservation Service
- Department of the Army
  - Army Corps of Engineers
- Department of Commerce
  - Economic Development Administration
  - National Bureau of Standards
  - National Oceanic and Atmospheric Administration
  - National Weather Service
- Department of Energy
  - Assistant Secretary for Conservation and Renewable Energy
  - Federal Energy Regulatory Commission
  - Federal Power Administrations

TABLE 9-3--Continued

Executive Offices (continued)

- Department of Health and Human Services
  - Agency for Toxic Substances and Disease Registry
  - National Center for Toxicological Research
  - National Institute of Environmental Health Sciences
- Department of Housing and Urban Development
  - Assistant Secretary for Community Planning and Development
- Department of the Interior
  - Assistant Secretary for Water and Science
  - Bureau of Indian Affairs
  - Bureau of Land Management
  - Bureau of Mines
  - Bureau of Reclamation
  - Fish and Wildlife Service
  - Geological Survey
  - Minerals Management Service
  - National Park Service• Department of Justice
  - Land and Natural Resources Division
- Department of State
  - Bureau of Oceans and International Environmental and Scientific Affairs
- Department of Transportation
  - United States Coast Guard
  - Saint Lawrence Seaway Development Corporation

Independent Establishments and Government Corporations

- Environmental Protection Agency
  - Assistant Administrator for Water
- Federal Emergency Management Agency
- General Services Administration
  - Public Buildings Service
- Interstate Commerce Commission
- Panama Canal Commission
- Small Business Administration
  - Loan Programs
  - Pollution Control Financing Program
- Tennessee Valley Authority

Quasi-Official Agencies

- Smithsonian Institution
  - Smithsonian Environmental Research Center
  - Smithsonian Tropical Research Institute

Bilateral Organizations

- International Boundary and Water Commission, United States and Mexico
- International Joint Commission, United States and Canada

Source: Authors' construct. For more information on these offices, see appendix C.

TABLE 9-4

FEDERAL WATER DATA COLLECTION PROGRAMS

	Federal Agencies*									
	Government Agencies						Independent Agencies			
Program Areas	USDA	DOC	DOD	DOE	DOI	DOT	EPA	IBWC	NRC	TVA
Surface water	X	X	X	X	X	X	X	X	-	X
Groundwater	X	-	X	X	X	X	X	X	-	X
Water quality	X	X	X	X	X	X	X	X	-	X
Water use	X	X	X	X	X	-	-	-	-	-
Envirnmntl. impact	X	-	X	X	X	X	X	-	-	X
Ecology	X	-	X	X	X	X	X	-	-	X
Management effects	X	-	X	X	X	X	X	-	-	X
Basin studies	X	-	-	-	X	X	X	-	-	X
Real-time sensing	X	X	X	-	-	X	X	-	-	X
Remote sensing	X	X	X	-	-	X	X	-	-	X
Data sensing	X	-	X	X	X	-	X	-	-	X
Instream use	X	-	-	-	X	-	-	-	-	-
Water rights	X	-	-	-	X	-	-	-	-	-
Floods	-	X	-	-	X	X	-	-	-	X
Energy	-	-	-	X	X	-	X	-	X	-
Nuclear	-	-	-	X	X	-	X	-	X	-
Precip. quality	-	-	-	-	X	-	X	-	-	X

Source: U.S. Geological Survey, *Plans for Water Data Acquisition by Federal Agencies Through Fiscal Year 1983* (Office of Water Data Collection, U.S. Geological Survey, 1982), 7.

* Key:
USDA - U.S. Department of Agriculture
DOC - Department of Commerce
DOD - Department of Defense
DOE - Department of Energy
DOI - Department of the Interior
DOT - Department of Transportation
EPA - Environmental Protection Agency
IBWC - International Boundary and Water Commission
NRC - Nuclear Regulatory Commission
TVA - Tennessee Valley Authority

The Federal Water Policy Commissions

The first federal water policy commission was the Water Resources Policy Commission (also known as the Cooke Commission), established by President Harry S. Truman in 1950.[9] Its assessment supported the sustained use of water to attain a high level of prosperity, the creation of major independent river basin commissions, the development of an overall multipurpose basin program, the collection of geological and hydrological data on water supply, and the enactment of a single statute applicable to all federal water resources activities and agencies.

Soon, federal water policy shifted from regional development concerns to the apportionment of an increasingly scarce resource, in part because of rapid industrialization.[10] The Senate Select Committee on National Water Resources (also known as the Kerr Committee), was created in 1959 and issued its recommendations two years later. It called for the federal government to prepare and update comprehensive development and management plans for the nation's major water resources regions, including biennial assessments. It also called for the states to take a more active role in water policy, for the federal government to establish a water research program, for greater efficiency in water use and development, and for increasing the public's awareness of the nation's water resources. The Water Resources Research Act of 1964 and the Water Resources Planning Act of 1965 followed.

In 1968 Congress created the National Water Commission. The report it issued in 1973 made more than two hundred recommendations for improving national water policy.[11] According to Foster and Rogers, the following finding by the commission can still be commended as the principal objective in addressing the nation's water resources needs:

> The Commission recommends the adoption of national policies which, within appropriate constraints of environmental protection and desired patterns of land use, will encourage

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[9] Foster and Rogers, *Federal Water Policy*, 22.
[10] Ibid., 25.
[11] Ibid., 27.

> the use of water in the most efficient and equitable way to meet the people's demands for goods and services.[12]

The commission contended that demands due to growth could and should be controlled, that priorities would shift away from development and toward preserving and enhancing water quality; that water resource planning should be linked to land planning; that economic approaches (including the principle that beneficiaries pay) would reduce losses, increase efficiencies, and advance conservation; and that the laws and institutions governing water resources should be reexamined. Finally, the commission tried to define the role of the federal government in water resource matters.

On June 6, 1978, President Jimmy Carter delivered his *Message to Congress on Water Policy Reform* in which he proposed policy initiatives designed to:[13]

- improve planning and efficient management of federal water resource programs to prevent waste and to permit necessary water projects which are cost-effective, safe, and environmentally sound to move forward expeditiously;
- provide a new, national emphasis on water conservation;
- enhance federal-state cooperation and improved state water resources planning; and
- increase attention on environmental quality.

In 1979, President Carter's *Water Resources Policy Study Task Force* advocated a role for the states in federal water project decisions as well as cost-sharing and price reforms.[14] It also asserted that the Water Resources Council should be responsible for applying evaluation standards to all federal water projects. These proposals represented a significant departure from past practices, especially from Congress's role in authorizing new projects. Some of the Carter reforms were heeded by the

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[12] National Water Commission (1973) as quoted in Foster and Rogers, ibid.
[13] *President's Message to Congress on Water Policy Reform*, in Wilson, *State Water Policy Issues*, Appendix A.
[14] Foster and Rogers, *Federal Water Policy*, 30.

Reagan administration, which focused on a "new federalism" for shifting costs and administrative responsibilities to the states.

The U.S. Water Resources Council consisted of the Secretaries of the Departments of the Interior (who served as chair), Agriculture, Army, Commerce, Energy, Housing and Urban Development, and Transportation and the Administrator of the EPA. Under the authority of the Water Resources Planning Act of 1965, the Council prepared two national water assessments. The second, published in 1978 under the chairmanship of Secretary of the Interior Cecil D. Andrus, became a focal point of the national water debate.[15] This assessment identified ten critical problems confronting the nation's water resources, and possible ways to resolve them.[16] The report concluded that, "In view of the long lead-time needed for planning, research, education, and implementation of programs. . . . a comprehensive, coordinated program is vital to the long-term national well-being."[17]

With the advent of the Reagan years, the Council was administratively terminated and is now listed as "inactive" in the *United States Government Manual*. Some of the slack in the federal data collection effort has been taken up by the U.S. Geological Survey.[18] However, with the demise of the Water Resources Council, the opportunity for planning and a coordinated national water program may have been seriously impaired. And as Foster and Rogers observed, many of the issues originally raised by the Cooke Commission remain on the forefront of the water debate.[19]

Water Resources Development

The history of water resources development in the United States, especially in the western region, is political, emotional, and today almost always controversial. Most water policy issues have a well-defined regional dimension because historically the East has been water-rich, while the West has been predominantly water-poor.[20] Western states have sought a major federal role in the development of water supplies for both agricultural and domestic purposes. As summarized in table 9-5, the conflict over water development among agencies of the federal government, established appropriators (such as ranchers and farmers), and native Americans is probably the most vivid example of the emotional content of the water issue.[21]

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[15] U.S. Water Resources Council, *The Nation's Water Resources 1975-2000* (Washington, DC: U.S. Water Resources Council, 1978).
[16] These are reported in chapter 2 of this report.
[17] U.S. Water Resources Council, *The Nation's Water Resources 1975-2000: Volume 2*, 2.
[18] See, for example, Wayne B. Solley, Charles F. Merk, and Robert R. Pierce, *Estimated Use of Water in the United States in 1985* (Washington, DC: U.S. Geological Survey, 1988).
[19] Foster and Rogers, *Federal Water Policy*, 37.

Federal water projects include projects for storage, flood control, navigation, hydroelectric power production, and other purposes. The Bureau of Reclamation of the Department of the Interior and the U.S. Army Corps of Engineers are responsible for much of the planning, financing, and construction of the nation's major water development projects. The Soil Conservation Service and the Tennessee Valley Authority are also involved in many federal water projects.

Many expensive federal water projects were undertaken because political considerations preempted economic ones.[22] Bureaucratic policies and interagency competition contributed to their approval. Congress, of course, authorized project after project in what some believe to be the essence of "pork-barrel politics."[23] Proponents of federal water projects "argue that water supply development has been and remains a critical factor in

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[20] John L. Moore, et al., *The Nation's Water Supply: An Overview of Conditions and Prospects* (Washington, DC: Congressional Research Service, Library of Congress, 1986), 7.

[21] Allen V. Kneese and F. Lee Brown, *The Southwest Under Stress: National Resource Development Issues in a Regional Setting* (Baltimore, MD: Resources for the Future and Johns Hopkins University Press, 1981).

[22] Kenneth D. Frederick, "Water Policies and Institutions," in David H. Speidel, Lon C. Ruedisili, and Allen F. Agnew, eds., *Perspectives on Water: Uses and Abuses* (New York: Oxford University Press, 1988), 337.

[23] Marc Reisner, *Cadillac Desert: The American West and Its Disappearing Water* (New York: Viking, 1986). In a chapter entitled "The Peanut Farmer and the Pork Barrel," Reisner remarks: "To a degree that is impossible for most people to fathom, water projects are the grease gun that lubricates the nation's legislative machinery. Congress without water projects would be like an engine without oil; it would simply seize up. . . . In the Congress, water projects are a kind of currency, like wampum, and water development itself is a kind of religion." (319-20).

TABLE 9-5

ELEMENTS OF WATER CONFLICT

Party to Dispute	Interests or Objectives	Emotional Intensity of Interest
Established Appropriators	Prevention of economic loss (all appropriators)	Commercial interest, diligently protected
	Maintenance of physical availability of water and associated way of life (e.g., small farmers)	Fervent defense of home and lifestyle.
Indians	Economic development	Fundamental and tangible interest, strongly advocated.
	Revenue generation	Budgetary interest, administrative convenience.
	Symbol of Indian aspirations	Overriding interest, compelling and considered worthy of great sacrifice.
Federal	Expansion of water supply for federal installations	Program level necessity, partial alternatives possible.
	Trustee responsibility to Indians	Persistently advocated within those governmental agencies and divisions to which responsibility assigned; degree of intensity varies with individual.
	Water manager and financier	Bureaucratic purpose with strong political overtones.
	Policy making	Varies with degree of national resolve.

Source: Allen V. Kneese and F. Lee Brown, *The Southwest Under Stress: National Resource Development Issues in a Regional Setting* (Baltimore, MD: Resources for the Future and Johns Hopkins University Press, 1981), 85.

sustaining growth in regions of the South and West."[24] In effect, they contend that the way to resolve conflicts among users is more water projects.

Critics say that, because of its developmental bias, "The federal government has for too long subsidized unwise, economically inefficient, and environmentally destructive water-engineering projects, which in turn have permitted and stimulated unwise settlement and development."[25] Others contend that many of the federal water projects contributed to the inefficient use of the nation's water resources.[26] They argue that federally supplied water tends to be grossly underpriced, causing a significant burden on the federal budget and extravagant use instead of conservation.

In addition to constructing new projects, the federal government also plays a role in water transfers. Historically, the Bureau of Reclamation restricted the diversion of water from federal storage projects that were devoted solely to agricultural use.[27] A policy adopted in 1989 allows water transfers in the interest of improving the efficient use of existing facilities. According to the new policy, federal involvement will be limited to those transfers affecting federal projects or federally owned water rights, and to measures that mitigate the adverse environmental impacts of transfers. The Bureau will initiate transactions only involving Indian water rights, conflicts over rights, or transfers that help avoid federal investments in providing water supplies. The policy also emphasizes state primacy in water allocation and management.

Several forces have made it more difficult to gain approval for major federal water resource development projects. First, the incremental costs of development are high because the more productive reservoir sites have

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[24] Wilson, *State Water Policy Issues*, 23.

[25] Rockefeller Brothers Fund Task Force, as reported in Leonard U. Wilson, *State Water Policy Issues* (Lexington, KY: The Council of State Governments, 1978), 23.

[26] Frederick, "Water Policies and Institutions," in Speidel, Ruedisili, and Agnew, eds., *Perspectives on Water*, 337.

[27] American Water Works Association, "Bureau Adopts New Water Rights Policy," *Mainstream* (February 1989), 5.

already been developed.[28] In eras of deficit spending, cost is always a central issue. Second, a significant segment of society and its representatives in government place a higher value on instream uses for recreation, wildlife, and aesthetics.[29] Third, there is a growing recognition that reform in pricing and cost-recovery can help keep supply and demand proximate. Fourth, there is also a growing awareness that demand management and conservation may be a viable alternative to capacity additions. Fifth, the environmental movement, institutionalized with the passage of the National Environmental Policy Act of 1970, provided a vehicle for thwarting many water resources projects.[30]

Federal agencies continue to invest heavily in water resource development. The Water Resources Development Act of 1986 authorized more than 270 federal water projects, as well as numerous studies and project modifications, at a cost to the federal government of about $16.5 billion.[31] In a break from the past, however, it also required extensive cost-sharing with nonfederal sponsors, consistent with the "new federalism" approach of shifting costs to state and local governments or to the private sector.

The Federal Role in Local Supply

The federal government directly affects local water supply in three areas: funding projects to augment supplies, providing financial assistance for wastewater treatment, and setting safe drinking water standards.[32] Water storage is included in many multipurpose federal projects. The federal government has provided grants and loans to municipal utilities to construct distribution and treatment works through the Farmers Home Administration, Economic Development Administration, Community Development Block Grant program, Department of Housing and Urban Development, and

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[28] John L. Moore, et al., *The Nation's Water Supply: An Overview of Conditions and Prospects* (Washington, DC: Congressional Research Service, Library of Congress, 1986), 2.

[29] Ibid.

[30] The proposal by the U.S. Army Corps of Engineers to construct the Cross-Florida Barge Canal is an excellent case in point.

[31] Foster and Rogers, *Federal Water Policy*, 34.

[32] Moore, et al., *The Nation's Water Supply*.

Appalachian Regional Commission. The federal government has also provided substantial funding for the construction of wastewater treatment facilities, principally through the grant-in-aid program under the Clean Air Act, administered by the Environmental Protection Agency (EPA). These grants fund only certain types of projects, such as treatment plants, interceptor sewers, and infiltration/inflow.

Finally, the federal role in recent years has been most visible, and perhaps most controversial, in the area of drinking water standards under the auspices of the EPA.[33] In the early 1970s, the focus of water quality regulations was on limiting municipal and industrial point discharges (from a pipe) and controlling conventional pollutants (such as organic wastes, sediment, bacteria and viruses, nutrients, and oil and grease). The Safe Drinking Water Act of 1974 established standards and required the removal of chemical and biological contaminants and turbidity from water supplies. In the 1980s, Congress and the EPA turned their attention to controlling toxic pollutants (such as heavy metals, organic chemicals and pesticides) and nonsource discharges (such as agricultural runoff and mining wastes). The 1986 amendments to the Safe Drinking Water Act are having a substantial impact on water suppliers.[34] Compliance with drinking water standards is costly, particularly for small water suppliers that do not enjoy economies of scale. In this regard, federal policy contributes to the diminishing availability of inexpensive water at the local level.

Drought and Conservation

The federal role in drought management has been generally reactive. Federal drought relief during 1974-1977 is estimated at more than $8 billion.[35] The following programs accounted for the majority of federal drought relief money during the middle-1970s:

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[33] Ibid.

[34] See Vivian Witkind Davis and Ann P. Laubach, *Surface Water Treatment Rules and Affordability: An Analysis of Selected Issues in Implementation of the 1986 Amendments to the Safe Drinking Water Act* (Columbus, OH: The National Regulatory Research Institute, 1988) and Patrick C. Mann and Janice A. Beecher, *Cost Impact of Safe Drinking Water Act Compliance for Commission-Regulated Water Utilities* (Columbus, OH: The National Regulatory Research Institute, 1989).

- Farmers Home Administration's Emergency Loan Program ($3.23 billion) and Community Program Loans and Grants ($225 million)
- Small Business Administration's Disaster Loan Program ($1.4 billion)
- Agricultural Stabilization and Conservation Service's Disaster Payments Program ($1.8 billion)
- Department of Commerce's Community Emergency Drought Relief Program ($175 million)
- Department of the Interior's Emergency Fund and Emergency Drought Programs ($130 million)

A key federal response to drought is the national crop insurance program. In addition, the federal government is responsible for monitoring drought conditions, drought early warning, and drought declaration. However, there is no federal drought plan nor routine post-drought evaluation.[36] Two pieces of legislation were passed in response to the 1988 drought.[37] These provided disaster relief and funded drought-mitigation activities under the Secretary of the Interior. The 1988 drought was evaluated in brief form by the President's Interagency Drought Policy Committee.[38]

In these areas, the United States lags behind other developed nations in its drought planning and response capabilities. In Great Britain, for example, the Drought Act of 1976 permitted river basin authorities to prohibit residential and commercial water use for nonessential purposes, implement further prohibitions during severe shortages, and develop new water supplies.[39] The Act also recommended the establishment of advisory committees comprised of major industrial and public users that would be responsible for specifically defining the provisions of the Act as well as planning further restrictive actions should they become necessary.

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[35] These data are reported in Donald A. Wilhite, "The Role of Government in Planning for Drought: Where Do We Go From Here?" in Donald A. Wilhite and William E. Easterling, eds., *Planning for Drought: Toward a Reduction of Societal Vulnerability* (Boulder, CO: Westview Press, 1984), 428.

[36] Wilhite, "The Role of Government in Planning for Drought," in Wilhite and Easterling, eds., *Planning for Drought*.

[37] See chapter 5.

[38] *The Drought of 1988: Final Report of the President's Interagency Drought Policy Committee* (Washington, DC: U.S. Government Printing Office, 1988). For the Committee's appraisal, see chapter 5.

Conservation is not a new concept in federal policy made evident by the Water Resources Planning Act of 1965 which listed its goals as follows:

> [To] encourage the conservation, development, and utilization of water and related land resources of the United States on a comprehensive and coordinated basis by the Federal Government, States, localities, and private enterprise with the cooperation of all affected Federal agencies, States, local governments, individuals, corporations, business enterprises, and others concerned.[40]

Authorization and appropriation legislation for many federal agencies includes conservation provisions. Two recent bills also are designed to promote water conservation at the federal level. The National Plumbing Products Efficiency Act of 1989 would establish national efficiency standards for toilets, urinals, showerheads, and lavatory and kitchen faucets.[41] The bill also would enable the Secretary of Commerce to establish standards for other plumbing products. As in the establishment of efficiency standards for electrical appliances, this legislation may benefit not only consumers but fixture manufacturers adversely affected by the enactment of standards that differ from state to state and locality to locality. Low-flush toilets are mandated at present for new construction and replacements in Massachusetts and in several cities; many more jurisdictions, particularly those with water shortage problems, may adopt similar legislative measures.

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[39] Anne M. Blackburn, "Management Strategies: Dealing with Drought," in American Water Works Association, *Water Conservation Strategies* (Denver, CO: American Water Works Association, 1980), 17.

[40] Water Resources Planning Act of 1965, as reported in Foster and Rogers, *Federal Water Policy*, 3.

[41] "The National Plumbing Products Efficiency Act of 1989," *Congressional Record*, House Resolution 1185 (S. 583), Vol. 135, No. 20, 1 March 1989. An earlier version of this legislation was the proposed National Plumbing Fixtures Efficiency Act of 1988 (S. 2896/H.R. 5497).

The Municipal and Industrial Water Conservation Act of 1989 was proposed in response to recurring droughts in many parts of the country, and the belief that demand will exceed reliable supplies for a significant percentage of the nation's municipal water systems in the 1990s.[42] The bill promotes the wise and efficient use of the nation's water resources. It calls for creating an Office of Water Conservation within the Environmental Protection Agency (EPA), coordinating federal policy through the EPA, providing technical assistance to states, municipalities, businesses, and institutions, establishing a national clearinghouse on water conservation, establishing an advisory council on water conservation, and requiring all federal environmental impact studies to consider water conservation. If enacted, this legislation would help define the nation's water supply and conservation policies in more explicit terms.

Interstate Water Issues

Title II of the Water Resources Planning Act of 1962 provided for the establishment of six interstate river basin commissions: the New England, Great Lakes, Ohio, Upper Mississippi, Missouri, and Pacific Northwest.[43] The commissions were created to perform water resource planning and management functions in cooperation with federal agencies. Basin plans were intended to be comprehensive and coordinate planning with regard to all water and water-related problems in the basin regions. Federal funding, however, fell far short of what was needed to meet the mandate of the 1962 legislation. Moreover, the Act envisioned federal participation and coordination through the now-dormant U.S. Water Resources Council. Thus, the commissions have become neither an effective "nationwide network" nor an "integral part of the national water policy machinery."[44] Nevertheless, the interstate commissions have provided pragmatic and focused analyses of issues affecting the river basins.

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[42] "The Municipal and Industrial Conservation Act of 1989," Senate Bill 1422 (H.R. 3099), *Congressional Record*, Vol. 135, No. 103, 27 July 1989. Related legislation was the proposed National Water Conservation Act of 1988 (S. 2904/H.R. 5496).

[43] Leonard U. Wilson, "Intergovernmental Coordination of Water Resource Planning", in Wilson, *State Water Policy Issues*, Appendix E.

[44] Ibid., 63.

Today, there are fifteen major interstate water agencies established by interstate compacts through which states agreed to allocate and manage a common water resource. These agencies, identified in table 9-6, act in an advisory or enforcement capacity for regions of the country. Forty-one states and the District of Columbia belong to one or more of these interstate commissions. The federal government is a signatory party in some of the compacts, such as those for the Delaware and Susquehanna river basins. Interstate compacts, which require the approval of Congress under the consent provision of the Constitution, are of four types:[45]

TABLE 9-6

INTERSTATE WATER AGENCIES

Interstate Agencies (Year Established)
Advisory Agencies
New England Governors' Conference, Inc. (1936)
Interstate Commission on the Potomac River Basin (1940)
Great Lakes Commission (1955)
Klamath River Compact Commission (1957)
Western States Water Council (1965)
Missouri Basin States Association (1981)
Ohio River Basin Commission (1981)
Upper Mississippi River Basin Association (1981)
Agencies with Enforcement Powers
Interstate Sanitation Commission (1936)
New England Interstate Water Pollution Control Commission (1947)
Ohio River Valley Sanitation Commission (1948)
Upper Colorado River Commission (1948)
Delaware River Basin Commission (1961)
Tahoe Regional Planning Agency (1969)
Susquehanna River Basin Commission (1971)

Source: The Council of State Governments, *Book of the States, 1988-89 Edition* (Lexington, KY: The Council of State Governments, 1988), 412-13. See appendix C for member states and notations.

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[45] Black, *Conservation of Water and Related Land Resources*, 28-33.

- Water allocation compacts (such as the Colorado River compact);
- Pollution control compacts (such as the Klamath River compact);
- Planning flood control compacts (such as the Red River of the North compact); and
- Comprehensive regulatory and project development compacts (such as the Susquehanna River compact).

There are opposing positions on the issue of whether or not water management and planning should be centralized on an interbasin or interstate basis. Emergencies, such as droughts, may call for more centralized approaches. Coordination, however, requires cooperation. Anne M. Blackburn notes the lack of enthusiasm for the Interstate Commission on the Potomac River Basin, but cautions that, "the opposite extreme, sixteen separate jurisdictions and twenty water-supply purveyors trying, without prior planning, to make decisions, implement action programs, and maintain communication with each other during a water-supply emergency leaves one rather uneasy. . . ."[46] This study concludes that, "Judicious and expeditious preliminary planning, agreement, and actions could do much to avoid mutually dysfunctional chaos and to stimulate constructive cooperation." Planning may actually reduce the amount of local power that must be relinquished in a crisis situation and may help minimize cost impacts.

The diversion of water to water-poor regions is frequently advocated as a long-term solution to perennial shortages. Major diversions between river basins and between states tend to be conflictual, even bitter.[47] The Northwest, for example, has generally opposed diversion to the Southwest. Some say that such transfers are, in a sense, "robbing Peter to pay Paul."[48]

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[46] Blackburn, "Management Strategies," in American Water Works Association, *Water Conservation Strategies*, 24.

[47] Harvey O. Banks, Jean O. Williams, and Joe B. Harris, "Developing New Water Supplies," in Ernest A. Engelbert and Ann Foley Scheuring, eds., *Water Scarcity: Impacts on Western Agriculture* (Berkeley, CA: University of California Press, 1984), 109-25.

[48] Warren Viessman, Jr. and Christine DeMoncada, *State and National Water Use Trends to the Year 2000* (Washington, DC: Congressional Research Service, Library of Congress, 1980), 283.

Others oppose these projects on environmental grounds. While some diversions--such as the State Water Project and the Federal Central Valley Project, both in California--are entirely intrastate, many are interstate and some are international. The Central Arizona Project, for example, involves diversions from the Lower Colorado River to California and Arizona. Diversions to western lands from the Columbia River Basin, the Missouri River Basin, the Western Arkansas Basin, and the Mississippi River System also have been proposed. The large-scale transfers envisioned by some of these plans could dramatically alter water-use trends in the arid regions. Their implementation, however, depends largely on whether interstate and interbasin conflicts can be resolved.

Absent clear federal signals, the national role of interstate policy is uncertain. However, because the states share water resources, the need for coordination in planning and resource development is obvious. Water flows freely across state boundaries and many water resource problems, including drought, tend to be regional in nature. Some solutions, such as water diversions, are regional as well. Thus, the potential for interstate agencies to play a more prominent role in water resources policy, particularly in times of scarcity, may become increasingly apparent.

The State Role

A paradox of water resource policy is that while the federal role is pervasive, primacy belongs to the states. The Water Supply Act of 1958 declared that it was "the policy of Congress to recognize the primary responsibilities of the States and local interests in developing water supplies for domestic, municipal, industrial, and other purposes," while promising federal participation and cooperation in developing supplies connected with federal water projects.[49] Indeed, the federal government has reinforced the primacy role of the states in many areas. The EPA, for example, relies heavily on the states to implement the Safe Drinking Water Act. Thus, despite the pervasive federal role and the preemptive nature of federal law, the states have asserted primacy in many facets of water policy, including planning, management, and regulation.[50] Like the federal government, however, state policymaking in the water resource area can sometimes appear fragmented and pluralistic.

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[49] *Water Supply Act of 1958* as reported in Moore et al., *The Nation's Water Supply*, 41.

A 1978 policy statement by the National Governor's Association sets forth eleven broad principles that encapsulate the states' view of water policy roles and responsibilities in the federal system:[51]

- States have primary responsibility for water management.
- The proper federal role is to establish a framework of national objectives and to assist states in the development of programs to meet those objectives.
- Water management should be more comprehensively approached at all government levels.
- Federal actions must be consistent with state and interstate water plans and programs.
- There must be continuity in federal support for water management programs.
- Greater flexibility in the federal support system for water management is needed.
- Criteria for federal water program and project evaluation should be refined and uniformly applied.
- Financing, cost-sharing, and cost-recovery policies should be revised to eliminate inequities toward water solutions and to promote equal consideration of structural and nonstructural alternatives.
- Water conservation must be a fundamental consideration.
- Federally supported water research should be expanded and made more responsive to state concerns.
- Indian and federal reserve water-rights claims should be addressed initially within the framework of the state legal systems.

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[50] Wilson, *State Water Policy Issues*.
[51] *National Governors' Association Position on National Water Policy* as reported in Wilson, *State Water Policy Issues*, Appendix C.

One of the key elements of state primacy is the system of water law. Each state relies on a legal tradition that governs the withdrawal and use of water. Naturally, legal issues can become a focal point when water is in short supply.

Water Law, Rights, and Transfers

Water supplies, according to Kenneth D. Frederick, are common-property resources because as "water flows from one property to another, supplies are accessible to many but belong to no one until they are withdrawn for use."[52] When two countries are involved, water becomes the subject of treaties; when two states are involved, water becomes the subject of an interstate compact.[53] In most other instances, water withdrawals are governed by state water law, which encompasses a complex configuration of statutory, administrative, and common-law components.

Fundamental to water law is the concept of water rights. A water right, according to C. W. Fetter, "is not legal title to the water, but the legal right to use it in a manner dictated by state law."[54] There also may be federal constraints to the exercise of water rights, particularly when interstate conflicts arise. Although the breadth of water law is generally beyond the scope of this investigation, decisionmakers at all levels must recognize the potentially significant impact water law may have on planning for water resource development and supplies for all sorts of water uses.

Bonnie Colby Saliba and David B. Bush identify five basic type of water rights: riparian, appropriative, use permits, allotments, and mutual stock.[55] Water law in the eastern United States traditionally relied on the system of riparian rights, through which the right to use surface water belongs to those who owned the contiguous land for use on that land. When supplies are adequate, reasonable use is allowed as long as downstream flows are not impaired. When supplies are inadequate, riparian users share in reducing their consumption.[56] However, the courts have generally recognized a hierarchy of uses whereby domestic uses take priority over agricultural uses, which in turn take priority over industrial uses.[57]

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[52] Frederick, "Water Policies and Institutions," in Speidel, Ruedisili, and Agnew, eds., *Perspectives on Water*, 335.

[53] Gary D. Weatherford and Helen M. Ingram, "Legal-Institutional Limitations on Water Use," in Ernest A. Engelbert and Ann Foley Scheuring, *Water Scarcity: Impacts on Western Agriculture* (Berkeley, CA: University of California Press, 1984), 53. See also, Gary D. Weatherford, ed., *Water and Agriculture in the Western U.S.: Conservation, Reallocation, and Markets* (Boulder, CO: Westview Press, 1982).

[54] C. W. Fetter, *Applied Hydrogeology* (Columbus, OH: Merrill Publishing Company, 1988, Second Edition), 453.

[55] Bonnie Colby Saliba and David B. Bush, *Water Markets in Theory and Practice* (Boulder, CO: Westview Press, 1987), 57-59.

Key characteristics of water law for the western states are summarized in table 9-7. Most western states emphasize appropriative rights, which evolved in arid and semiarid regions to allow the reassignment of water rights for the diversion of water for "beneficial" and "continuous" uses. Under appropriative rights, beneficial use creates the "right to take" without restriction as to the location of use.[58] Appropriative rights can be lost through abandonment. Also, a senior user may force subsequent users to cease appropriating if the source cannot support more than one user.

Each state, however, is somewhat unique. California, for example, developed the correlative rights rule, which combines features of riparian and appropriative rights, and which recognizes the watershed as the basic management unit.[59] Some states employ use permits to recognize appropriative rights. Most western states also apply the rule of prior appropriation to groundwater withdrawals. Allotments, according to the doctrine of mutual prescription, are used to allocate a water resource among multiple users through a formula developed by some authoritative governing board. Similarly, mutual stocks are used by parties to stake a claim to a share of a water resource.

Prior appropriation is limited by the Winters Doctrine, which gives priority to the water rights of Native Americans that became effective with the establishment of reservations. A substantial body of legal analysis concerns Native American water rights and the ramifications of the Winters

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[56] Frederick, "Water Policies and Institutions," in Speidel, Ruedisili, and Agnew, eds., *Perspectives on Water*, 335.

[57] Charles Donahue, Jr., Thomas E. Kauper, and Peter W. Martin, *Cases and Materials on Property* (St. Paul, MN: West Publishing, 1974), 392.

[58] Ibid.

[59] Black, *Conservation of Water and Related Land Resources*, 27.

TABLE 9-7

KEY CHARACTERISTICS OF WATER LAW FOR THE WESTERN STATES

State	Surface Water	Groundwater
Alaska	Appropriation/permit	Appropriation/permit
Arizona	Appropriation/permit	Highly discretionary permit system (percolating waters); appropriation/permit (subterranean streams)
California	Appropriation-riparian (reasonable use)/permit	Correlative rights/ appropriation/conjunctive management
Colorado	Appropriation/permit	Appropriation/permit
Hawaii	Unique water rights system based on ancient customs	Designated area/permit; artesian; correlative rights/ reasonable use
Idaho	Appropriation/permit	Reasonable use/permit; permit required for critical and noncritical areas
Kansas	Appropriation-riparian (reasonable use)	Appropriation/permit
Montana	Appropriation/permit	Reasonable use/permit; permit required for critical and large consumptive uses in noncritical areas
Nebraska	Appropriation/permit/ some riparian rights persist	Reasonable use/permit
Nevada	Appropriation/permit	Appropriation/permit; permit required for critical and noncritical areas
New Mexico	Appropriation/permit	Appropriation/permit
North Dakota	Appropriation/permit/ preexisting riparian rights confirmed	Appropriation/permit

TABLE 9-7--Continued

State	Surface Water	Ground Water
Oklahoma	Appropriation-riparian (reasonable use)	Appropriation/permit
Oregon	Appropriation/permit	Appropriation/permit
South Dakota	Appropriation/permit some riparian rights persist	Appropriation/permit
Texas	Appropriation/permit/ preexisting riparian rights confirmed	Absolute ownership
Utah	Appropriation/permit	Appropriation/permit
Washington	Appropriation/permit	Appropriation/permit
Wyoming	Appropriation/permit	Appropriation/permit permit required for critical and noncritical areas

Source: Gary D. Weatherford and Helen M. Ingram, "Legal-Institutional Limitations on Water Use," in Ernest A. Engelbert and Ann Foley Scheuring, *Water Scarcity: Impacts on Western Agriculture* (Berkeley, CA: University of California Press, 1984), 56 and 61.

Doctrine.[60] Indian claims to western water are potentially large and could disrupt the entire allocation system established by the states.[61] Some analysts speculate that there also is a potential for the federal government to usurp state laws and take unappropriated waters. In doing so the government may jeopardize existing appropriations and investments.[62]

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[60] See, for example, Richard B. Collins, "Indian Reservation Water Rights" and Steven J. Shupe, "Water Management in Indian Country," *American Water Works Association Journal* 78, no. 10 (October 1986).

[61] Frederick, "Water Policies and Institutions," in Speidel, Ruedisili, and Agnew, eds., *Perspectives on Water*, 339.

[62] Black, *Conservation of Water and Related Land Resources*, 27.

Appropriative water rights also determine priority uses. For example, public supply normally takes priority over irrigation, which takes priority over energy production and other instream uses, such as recreation and fisheries protection.[63] Some analysts suggest that priorities can be skewed in western water law and that the appropriations doctrine, despite the concept of beneficial use, can discourage conservation because of a "use-it-or-lose-it" philosophy.[64] The courts recently have invoked a public trust doctrine that limits the private use of water for the purpose of environmental preservation.[65] Differences over defining the public interest are likely to have a continuing effect on the water rights debate.

Water transfers only add to the complexity of water rights issues. Larry Morandi cites several examples of legislative responses to this issue.[66] California law provides for wheeling water through an unused portion of public conveyance facilities at a fair rate of compensation. Washington law exempts temporary water transfers from public notice and environmental impact assessment requirements during periods of drought. Montana law requires approval of water transfers in excess of 4,000-acre-feet per year and 5.5-cubic-feet per second by the Department of Natural Resources and Conservation in accordance with the following criteria:[67]

- The existing demands on the state water supply, as well as projected demands of water for future beneficial purposes, including municipal water supplies, irrigation systems, and minimum streamflows for the protection of existing water rights and aquatic life.

- The benefits to the applicant and the state.

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[63] James C. Wade, "Efficiency and Optimization in Irrigation Analysis," and Joel R. Hamilton and Norman K. Whittlesey, "Energy and the Limited Water Resource: Competition and Conservation," in Norman K. Whittlesey, ed., *Energy and Water Management in Western Irrigated Agriculture* (Boulder, CO: Westview Press, 1986).

[64] Frederick, "Water Policies and Institutions," in Speidel, Ruedisili, and Agnew, eds., *Perspectives on Water*, 336.

[65] C. W. Fetter, *Applied Hydrogeology*, 454.

[66] Larry Morandi, *Reallocating Western Water: Equity, Efficiency and the Role of Legislation* (Denver, CO: National Conference of State Legislatures, 1988).

[67] Montana Code Ann., Section 85-2-402, as reported in Larry Morandi, *Reallocating Western Water*, 23.

- The effects on the quantity and quality of water for existing uses in the source of supply.
- The availability and feasibility of using low-quality water for a specific purpose.
- The effects on private property rights by any creation of or contribution to saline seep.
- The probable significant adverse environmental impacts of the proposed use of water.

Thus, state policies have the potential either to facilitate or hinder the development and use of water supply alternatives, such as transfers. What effect they have may depend on the state water planning process.

Planning and Conservation

As in the case of water law, states vary considerably in their water resources planning capability. With a diminishing emphasis on the federal role beginning with the Carter administration, state water planning and management in water is receiving greater attention. Table 9-8 summarizes the planning status of each state as of 1981.[68] Though state mandates vary, most provide for comprehensive water *quantity* planning. In many cases, water *quality* planning or management also plays a role in the state effort. Planning in some states is both integrated and comprehensive.

A 1983 U.S. Army Corps of Engineers survey identified some of the state water supply initiatives (reported in table 9-9).[69] At that time, nineteen states had completed multipurpose framework studies to serve as state water plans. More than half of the states had implemented a water conservation effort, particularly in the areas of technical assistance and public education. Seventeen encouraged municipal drought planning. Some states

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[68] Weatherford and Ingram, "Legal-Institutional Limitations on Water Use," in Engelbert and Scheuring, eds., *Water Scarcity: Impacts on Western Agriculture*.
[69] U.S. Army Corps of Engineers and Pennsylvania Bureau of Water Resources Management, *The State of the States in Water Supply/Conservation Planning and Management Program* (Fort Belvoir, VA: Institute for Water Resources, U.S. Army Corps of Engineers, 1983), Appendix B.

TABLE 9-8

STATE WATER RESOURCE PLANNING CAPABILITY

State	Statutory Authority of Water Resources Planning and Management
Alabama	No express legislative mandate for comprehensive water resources planning and management
Alaska	Integrated, comprehensive water quantity management
Arizona	Integrated, comprehensive water quality and quantity planning
Arkansas	Comprehensive water quantity planning only
California	Integrated, comprehensive water quality and quantity management
Colorado	Comprehensive water quantity planning only
Connecticut	Integrated, comprehensive water quality and quantity planning
Delaware	Omnibus planning and management
Florida	Omnibus planning and management
Georgia	Integrated, comprehensive water quality and quantity planning
Hawaii	Comprehensive water quantity planning only
Idaho	Integrated, comprehensive water quality and quantity management
Illinois	No express legislative mandate for comprehensive water resources planning and management
Indiana	Comprehensive water quantity planning only
Iowa	Integrated, comprehensive water quality and quantity management
Kansas	Integrated, comprehensive water quality and quantity planning
Kentucky	No express legislative mandate for comprehensive water resources planning and management
Louisiana	No express legislative mandate for comprehensive water resources planning and management
Maine	No express legislative mandate for comprehensive water resources planning and management
Maryland	Integrated, comprehensive water quality and quantity management
Massachusetts	Comprehensive water quantity planning only
Michigan	No express legislative mandate for comprehensive water resources planning and management
Minnesota	Integrated, comprehensive water quality and quantity management
Mississippi	Integrated, comprehensive water quantity management
Missouri	Integrated, comprehensive water quality and quantity planning
Montana	Integrated, comprehensive water quality and quantity management
Nebraska	Comprehensive water quantity planning only
Nevada	Integrated, comprehensive water quality and quantity planning
New Hampshire	No express legislative mandate for comprehensive water resources planning and management

TABLE 9-8--Continued

State	Statutory Authority of Water Resources Planning and Management
New Jersey	No express legislative mandate for comprehensive water resources planning and management
New Mexico	No express legislative mandate for comprehensive water resources planning and management
New York	Integrated, comprehensive water quality and quantity planning
North Carolina	No express legislative mandate for comprehensive water resources planning and management
North Dakota	Integrated, comprehensive water quantity management
Ohio	No express legislative mandate for comprehensive water resources planning and management
Oklahoma	Integrated, comprehensive water quality and quantity management
Oregon	Integrated, comprehensive water quality and quantity management
Pennsylvania	Integrated, comprehensive water quality and quantity planning
Rhode Island	No express legislative mandate for comprehensive water resources planning and management
South Carolina	Comprehensive water quantity planning only
South Dakota	Integrated, comprehensive water quantity management
Tennessee	Comprehensive water quantity planning only
Texas	Integrated, comprehensive water quality and quantity planning
Utah	Comprehensive water quantity planning only
Vermont	Integrated, comprehensive water quality and quantity planning
Virginia	Integrated, comprehensive water quality and quantity planning
Washington	Omnibus planning and management
West Virginia	Integrated, comprehensive water quality and quantity planning
Wisconsin	Integrated, comprehensive water quality and quantity planning
Wyoming	Comprehensive water quantity planning only

Source: Kenneth Rubin (1981) as reported in Gary D. Weatherford and Helen M. Ingram, "Legal-Institutional Limitations on Water Use," in Ernest A. Engelbert and Ann Foley Scheuring, eds., Water Scarcity: Impacts on Western Agriculture (Berkeley, CA: University of California Press, 1984), 66.

TABLE 9-9

STATE WATER SUPPLY INITIATIVES

Initiative	Number of States
Water Plans Completed or in Progress, 1982	
Multipurpose framework studies	19
Regional or river basin studies	4
Single purpose water supply plans	4
Water policy assessments and analyses	4
Water program reports	2
Water Conservation Programs, 1982	
Technical assistance	29
Public education materials	28
Training and educational programs	17
Encouragement of municipal drought planning	17
Full-time conservation programs	15
Conservation demonstration projects	15
State drought contingency plans	6
Financial Assistance Through Grants & Loans, 1982	
Municipal and industrial water supply	12
Irrigation and other water development projects	11
Water supply and wastewater treatment	9
Technical Innovations, 1982	
Cloud seeding/weather modification	8
Irrigation	3
Leak detection	3
Conservation kits	3
Desalination	2
Watershed management	2
Recycling/reuse	1
Legislative Initiatives, 1980-1982	
Financing water supply projects	16
Water supply institutional improvements	13
Groundwater protection and management	10
Permitting registration programs	8
Water supply planning resolutions/bills	8
Water conservation programs	6
Water transfer and diversion	6
Water rights	4
Water supply project development	3
Water use restrictions	2

Source: Adapted from U.S. Army Corps of Engineers and Pennsylvania Bureau of Water Resources Management, *The State of the States in Water Supply/Conservation Planning and Management Program* (Fort Belvoir, VA: Institute for Water Resources, U.S. Army Corps of Engineers, 1983), Appendix B. Items are not mutually exclusive.

had provided financial assistance through grants and loans to water suppliers (and others) to further water planning efforts. Only a small number of states had invested in technical innovations in the water field. Only one, for example, reported involvement in the area of water recycling and reuse.

Finally, the survey revealed some attention was being paid in the legislative arena to areas such as financing water supply projects, improving institutional arrangements, and groundwater protection and management. Issues that were somewhat lower on the state agendas included conservation programs, water transfer and diversion, and water use restrictions. In the early 1980s, supply development, rather than conservation, may still have been favored. Nevertheless, the emergent interest in alternatives to traditional water supply solutions, as discussed at length in previous chapters, is obvious.

Another survey, reported in table 9-10, reports the components of the state conservation programs. Not surprisingly, the most frequent component

TABLE 9-10

ONGOING STATE WATER CONSERVATION PROGRAMS

Program	Number of States
Public education	18
Drought emergency plans by suppliers	17
Master water meters	17
Conservation plans or programs as state permit conditions	16
Leak controls in distribution systems	11
Water-saving plumbing	11
Conservation in public buildings	9
Customer water meters	9
Everyday conservation plans by water suppliers	8
Water pressure management for conservation purposes	5
Omnibus conservation legislation	5
Water pricing for conservation	3
Leak controls by water consumers	1
Tax breaks for household conservation devices	1

Source: New York State Senate Research Service Task Force on Critical Problems, as reported in Concern, Inc., *Drinking Water: A Community Action Guide* (Washington, DC: Concern, Inc., December 1986), 21.

concerns public education. A typical example of this type of effort is a brochure entitled *Use Water Wisely* published by the Pennsylvania Department of Environmental Resources.[70] Seventeen states reported that their plans included drought emergency plans by water suppliers. Sixteen required conservation plans or programs as a condition for obtaining a state permit. Relatively few states had explored other areas in their conservation programs. Water pricing, for example, was cited by only three as a conservation tool. Today, more states may be considering these options.

A state-by-state analysis of water conservation programs is provided in table 9-11. The results are based on a survey commissioned by the Department of the Interior in 1982. At that time, most of the initiatives had been adopted by only a few states. Plumbing codes, contingency planning, and groundwater management were reported most frequently. States that appear to have shown an interest in a wide range of water conservation strategies include California, Delaware, Maryland, Massachusetts, Minnesota, New Jersey, Pennsylvania, South Carolina, and Virginia. A set of recent legislative initiatives in Connecticut call for state water resource policy coordination, conservation actions by utilities, and plumbing standards.[71]

The survey results indicate that fewer than half of the states had adopted drought contingency plans by the early 1980s. Furthermore, the plans in place may have room for improvement, as noted by the U.S. Army Corps of Engineers:

> Drought planning is still in an embryonic stage. Few states have developed or articulated a statewide drought management policy. Two major approaches to the problem have been taken. Some states have developed statewide drought contingency plans. Others have developed handbooks for local municipalities to develop water shortage plans.[72]

There are, however, notable exceptions. Some states incorporate emergency planning in their state water supply plans. The New Jersey Water

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[70] Pennsylvania Department of Environmental Resources, "Use Water Wisely," March 1988.

[71] National Association of Regulatory Utility Commissioners, *Bulletin*, no. 39-1989 (September 25, 1989): 10.

[72] U.S. Army Corps of Engineers and Pennsylvania Bureau of Water Resources, *The State of the States in Water Supply*, B-5.

TABLE 9-11

COMPONENTS OF STATE WATER CONSERVATION PROGRAMS, 1982

	Program Components*												
ST	Public Education (1)	Plumbing Code (2)	Retrofitting (3)	Metering (4)	Leak Detection (5)	Rate Structures (6)	Contingency Planning (7)	Reuse & Recycling (8)	Outdoor Use (9)	Groundwater Mngmt. (10)	Industrial Use (11)	Agricultural Use (12)	Govt. Bldgs./ Grants (13)
AL	Part.	No	No	Yes	Yes	No	Part.	No	Yes	No	No	No	No
AK	No	No	No	Part.	No	No	No	No	No	Study	No	No	No
AZ	Part.	No	No	Part.	No	No	No	No	No	Yes	No	Yes	No
AR	No	Study	No	No	No	No	No	No	No	Study	No	Study	No
CA	Yes	Yes	Yes	No	Yes	Study	No	Yes	Study	Study	Yes	Part.	Yes
CO	No	No	No	Part.	No	No	Yes	No	No	Part.	No	Part.	No
CT	Study	No	No	No	No	No	Study	Yes	No	Study	Yes	No	No
DE	Yes	Yes	No	No	No	No	Yes	No	Study	Yes	Part.	Yes	No
FL	Part.	No	No	No	No	No	No	No	No	Yes	Part.	Part.	No
GA	No	Part.	No	No	No	No	No	No	No	Part.	No	No	No
HI	No	Part.	No	No	No	No	No	No	No	Yes	No	No	No
ID	No	Part.	No	No	No	No	Yes	No	No	Part.	No	Study	No
IL	Yes	No	No	No	No	No	Part.	No	No	No	No	No	Part.
IN	No	No	No	Part.	No	No	No	No	No	Study	No	No	No
IA	No	No	No	No	No	No	No	No	No	Yes	No	No	No
KS	No	No	No	No	No	No	Yes	Part.	No	Part.	No	No	No
KY	No	No	No	Yes	No	No	Study	No	No	No	No	No	No
LA	No	No	No	No	No	No	No	No	No	Part.	No	No	No
ME	No	Yes	No	No	No	No	Yes	No	No	No	No	No	No
MD	Yes	Yes	Part.	No	Part.	Study	Part.	Part.	Yes	Yes	Yes	Study	Part.
MA	Part.	Yes	No	Yes	Yes	Part.	Part.	No	No	Part.	No	No	Part.
MI	No	Yes	No	No	No	No	No	No	No	No	No	Part.	No
MN	Yes	No	Study	Yes	Yes	Study	Yes	Part.	Part.	Yes	Part.	Part.	No
MS	Part.	No	No	No	No	No	Part.	No	No	Yes	No	Part.	No
MO	No	No	Study	No	No	Study	No	No	No	No	No	No	No
MT	No	No	No	No	No	No	No	No	No	No	No	No	No
NE	No	No	No	No	No	No	No	No	No	Part.	No	No	No
NV	Part.	No	No	No	No	No	No	Part.	No	No	No	No	No
NH	No	Yes	No	No	No	No	No	No	No	No	No	No	No
NJ	Yes	Yes	Part.	No	Study	No	Yes	No	Part.	Part.	No	No	No

TABLE 9-11--Continued

	Program Components*												
ST	Public Education (1)	Plumbing Code (2)	Retrofitting (3)	Metering (4)	Leak Detection (5)	Rate Structures (6)	Contingency Planning (7)	Reuse & Recycling (8)	Outdoor Use (9)	Groundwater Mngmt. (10)	Industrial Use (11)	Agricultural Use (12)	Govt. Bldgs./Grants (13)
NM	No	Yes	No	Part.	No	No	No	No	No	Yes	No	Part.	No
NY	No	Yes	No	No	No	No	Study	No	No	No	No	No	No
NC	No	Yes	No	No	No	No	Part.	No	No	Yes	No	No	No
ND	Part.	No	No	Part.	No	No	Yes	Part.	No	Part.	No	Yes	No
OH	No	No	No	No	No	No	No	No	No	No	No	No	No
OK	Yes	No	Part.	No	No	No	Part.	No	Part.	Part.	No	No	No
OR	Study	Yes	Study	Study	Study	Study	Yes	No	Yes	Part.	No	No	No
PA	Yes	Yes	Study	No	Part.	Part.	Yes	Yes	No	Part.	No	No	Part.
RI	Part.	No	No	Yes	No	No	Study	No	No	Part.	No	No	No
SC	Part.	Study	Part.	No	No	No	Yes	No	No	Yes	No	Yes	No
SD	No	No	No	No	No	No	Yes	No	No	Yes	No	No	No
TN	Part.	No	No	No	No	No	Part.	No	No	Part.	No	No	No
TX	Part.	No	No	Yes	No	No	Study	Part.	No	No	No	Part.	No
UT	Part.	No	No	No	No	No	Study	No	No	Part.	No	Part.	No
VT	No	No	No	No	No	No	No	No	No	Part.	No	No	No
VA	Yes	Yes	No	No	Yes	No	Yes	Part.	Yes	Part.	No	No	Yes
WA	No	No	No	No	No	No	Part.	Study	No	Yes	No	Part.	No
WV	Part.	No	No	No	No	No	Study	No	No	No	No	No	No
WI	Part.	Yes	No	No	No	No	No	No	No	No	No	No	No
WY	No	Part.	No	Part.	No	No	No	Part.	No	Yes	No	No	No
Totals													
Yes	9	15	1	6	5	0	13	3	4	14	3	4	2
Part	14	4	4	7	2	2	9	8	3	17	3	10	4
Stdy	2	2	4	1	2	5	7	1	2	5	0	3	0
No	25	29	41	36	41	43	21	38	41	14	44	33	44

Source: Adapted from Brent Blackwelder and Peter Carlson, Survey of the Water Conservation Programs in the Fifty States: Model Water Conservation Program for the Nation (Washington, DC: Bureau of Reclamation, U.S. Department of the Interior, 1982), 2.

* Key:
Yes = State enacted program
Part. = Partial state program
Study = State enacted study or proposed plan
No = No state program at the time of the survey.

Supply Management Act of 1981, for example, empowers the state's Department of Environmental Protection to study and manage water resources, plan for emergencies and future water needs, and issue regulations to manage water during supply and quality emergencies.[73]

Some states use triggering mechanisms that allow regulations to be turned on and off during a water crisis.[74] These include Colorado, Delaware, Iowa, Kentucky, New York, and South Dakota as well as the Delaware River Basin Commission. Triggering mechanisms are tied to a drought index or some other measurement of hydrologic conditions. When conditions reach a certain severity, task forces are mobilized and activated. In the extreme case, an emergency situation is declared. The key to the use of triggering mechanisms is advance planning so that the response to drought is virtually automatic.

Governors play a leading role in dealing with catastrophes. The National Governors' Association (NGA) provides emergency preparedness guidelines for natural and man-made disasters.[75] The NGA recognizes four key components of emergency planning and management: mitigation, preparedness, response, and recovery. Mitigation stresses activities aimed at reducing the risk of disaster. Preparedness involves developing plans for managing the risk of disaster. Response refers to emergency assistance measures for reducing the primary and secondary impacts of disasters. Recovery means returning all systems to normal levels of operation.

During the 1988 drought, many states stepped up their drought warning and response systems, as well as their conservation efforts. In the past, the states may have paid too little attention to advance warning and long-term planning for drought, as revealed by one of the NGA case studies:

> The prime management difficulty arose out of the inability of farmers and state agricultural officials to perceive the warning signs of impending drought. The frequency of brief drought and the overall abundance of rain in recent years led most to believe that a severe drought would not strike.

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[73] Chapter 262 Laws of New Jersey 1981, adopted June 15, 1981.

[74] Margaret S. Hrezo, Phyllis G. Bridgeman, and William R. Walker, "Managing Droughts Through Triggering Mechanisms," *American Water Works Association Journal* 78, no. 6 (June 1986): 46-51.

[75] Hilary Whittaker, *State Comprehensive Emergency Management* (Washington, DC: National Governors' Association, 1978).

> Thus, the warnings of the Extension Service went unheeded. Only after the onset of severe drought did people begin to use the previously available conservation information.[76]

Of course, the need for state drought planning is not confined to the agricultural sector. In times of water shortage, all sectors may need to conserve in order to satisfy priority uses. Governors may be able to play a leading role in preparing the states for drought, but they cannot accomplish this task alone. The state planning effort may include the following government players:

- Governor
- State Legislature
- Committees and Task Forces
- Public Utility Commissions
- Department of Budget and Planning
- Department of Agriculture
- Department of Commerce
- Department of Health
- Department of Natural Resources
- Environmental Protection Agency

As noted in the previous chapter, integrated water resource planning may be a solution. In the case of state drought planning, integration may be possible across state agencies; among federal, state, and local governments; and with the private sector. Integration of state water policy objectives also may be important. For example, water supply, land use, environmental, natural resource, agricultural, and economic development considerations should be balanced so that competition among these interests does not undermine the state's overall planning objectives. States that have taken the lead in applying integrated approaches to water resource planning and regulation include California, Pennsylvania, and Rhode Island.

State public utility commissions are an important component of the state planning process. In fact, they provide one of the critical links to the private sector through the jurisdictional water utilities. One of the potential benefits of statewide coordination is consistency in policies toward water utilities, regardless of their ownership structure. In a severe water shortage, when questions of equity are often paramount, such coordination is essential.

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[76] Ibid., 258.

The Local Role

The local government role in water resources is also important. Most local water suppliers are municipal utilities. In such cases, local water supply policies can be implemented directly through the utility. For investor-owned water utilities, the influence of local mandates may be less direct, but they are not insignificant. Utilities may have to secure permits from local agencies for water supply projects. During a severe water shortage, investor-owned utilities may have to rely on local governments to impose water use restrictions, such as sprinkling bans.

Some examples of local water conservation initiatives are provided in table 9-12. These included landscaping (xeriscaping), retrofitting, education, pressure reduction, rehabilitation, and industry programs. Some local xeriscape programs are summarized in table 9-13. In many cases, the xeriscape program is a city utility function. California has a statewide program, although many of its cities have their own programs.

One area that has attracted considerable attention recently is plumbing codes. Advocates of plumbing code changes want replacement fixtures and new construction fixtures to meet low-water consumption standards. Table 9-14 compares the standards proposed under the National Plumbing Products Efficiency Act (S. 583/H.R. 1185) to those already existing or pending in some localities. The emergence of different state and local plumbing codes is one of the reasons behind the movement to adopt national standards. Most plumbing code proposals target toilets, the use of which accounts for more indoor water use than any other.

Water supply planning, especially in regions where water can be in short supply, is also likely to become a more integral part of land-use and urban planning. Some localities have established water conservation performance standards and goals. Bloomington, Minnesota and Los Angeles

TABLE 9-12

LOCAL WATER CONSERVATION INITIATIVES

Location	Type of Initiative
Aurora, CA	Landscaping; retrofitting.
Austin, TX	Landscaping; retrofitting.
Boston, MA	Studies of retrofitting, pressure reduction, and industrial water-savings potential.
Dallas, TX	Education; leak detection; seasonal pricing.
Denver, CO	Landscaping; education; leak detection; metering.
Fresno, CA	Landscaping; education.
Hyattsville, MD	Retrofitting; plumbing code; education; rates.
Las Vegas, NV	Education; landscaping; leak detection.
Los Angeles, CA	Incentives for business and industry; education; retrofitting; landscaping; seasonal rates.
Novato, CA	Landscaping; connection-fee discounts; irrigation.
Oakland, CA	Education; leak detection; retrofit landscaping; incentives for developers and customers.
Palm Springs, CA	Landscaping; irrigation.
Phoenix, AZ	Retrofitting; education; industrial program.
San Jose, CA	Retrofitting.
Santa Ana, CA	Landscaping.
Santa Barbara, CA	Advanced water-saving fixtures in new construction.
Seattle, WA	Retrofitting; education; rehabilitation.
Tucson, AZ	Education; landscaping.
Ventura, CA	Education; irrigation; landscaping.
West Palm Beach, FL	Irrigation; landscaping.

Source: William O. Maddaus, *Water Conservation* (Denver, CO: American Water Works Association, 1987), 8-10.

TABLE 9-13

XERISCAPE WATER CONSERVATION PROGRAMS

	Program Components*						
Location	Population (000)	Print Media/ Publications	Research and Savings	Regulations/ Ordinances	City Utility Function	Staff (FTE)	Approximate Budget
Arlington, TX	240	Y	P	-	-	1.0	$ 5,000
Arvada, CO	95	Y	Y	-	Y	.5	5,000
Aurora, CO	230	Y	Y	Y	Y	.3	AR
Austin, TX	1,000	Y	-	Y	Y	2.0	110,000
Boulder, CO	86	-	-	Y	Y	.2	AR
Brownsville, TX	125	Y	-	-	Y	-	AR
CA Xeriscape, Inc.	-	-	P	-	-	-	25,000
Denver, CO	650	Y	-	P	-	.5	60,000
Flagstaff, AZ	38	Y	-	P	Y	.1	15,600
Ft. Collins, CO	85	Y	Y	-	Y	.15	3,000
Ft. Worth, TX	1,000	Y	-	Y	Y	.3	31,000
Fresno, CA	280	Y	Y	Y	Y	1.0	70,000
Genesee, CO	3	Y	-	Y	-	-	AR
G. Basin, Reno, CO	300	Y	P	-	-	-	16,000
Greeley, CO	75	Y	-	-	-	.25	-
Lakewood, CO	130	Y	-	-	Y	.1	-
Longmont, CO	50	Y	Y	-	Y	.5	7,000
McKinney, TX	15	Y	-	-	-	-	-
N. Marin, CA	55	Y	Y	Y	Y	.5	50,000
East Bay, CA	1,100	Y	Y	P	Y	4.0	200,000
San Antonio, TX	1,200	Y	Y	-	Y	.5	17,000
San Diego, CA	1,500	-	-	-	-	-	-
S. CA Xeriscape	11,000	Y	-	-	-	.25	66,000
State of CA (DWR)	25,000	Y	Y	-	Y	2.0	400,000
Tucson, AZ	650	Y	P	Y	-	.5	21,000
Wheat Ridge, CO	30	Y	P	-	Y	.1	10,000

Source: The Front Range Xeriscape Task Force, *Xeriscape: Water Conservation Through Creative Landscaping* (Denver, CO: Metro Water Conservation, Inc., 1987), 27.

* *Key:*
FTE = full-time equivalent
Y = yes
P = proposed
AR = as required
- = not applicable

TABLE 9-14

PROPOSED, EXISTING, AND PENDING WATER-EFFICIENT PLUMBING STANDARDS BY JURISDICTION

Jurisdiction	Effective Date	Toilets (a)	Urinals (a)	Shower-heads (b)	Lavatory Faucets (b)	Kitchen Faucets (b)
Proposed National Standards						
United States	01/01/91	-	1.0	2.5	2.0	2.5
United States	01/01/92	1.6	-	-	-	-
Existing Standards						
Arizona						
Glendale	01/01/88	1.5	-	-	-	-
Tolleson	05/01/88	1.5	-	-	-	-
California						
Goleta	1983	1.6	-	2.0	2.0	2.0
Los Angeles	07/01/89	1.5	-	-	-	-
Monterey Penn.	08/13/87	1.5	-	-	-	-
Petaluma	06/06/88	1.5	-	-	-	-
Santa Monica	07/01/88	1.6	1.0	-	-	-
Sebastopol City	04/05/88	1.5	-	-	-	-
Windsor	9/86	1.5	-	-	-	-
Maryland						
Frederick	09/01/88	1.6	-	-	-	-
Massachusetts						
Statewide	03/02/89(c)	1.5	-	-	-	-
New York						
Highland	05/01/89	1.5	-	2.5	-	-
Statewide	01/26/88	-	1.0	-	-	-
Texas						
Austin County	12/09/82	-	1.0	-	-	-

TABLE 9-14--Continued

Jurisdiction	Effective Date	Toilets (a)	Urinals (a)	Shower-heads (b)	Lavatory Faucets (b)	Kitchen Faucets (b)
Pending Standards						
Arizona						
Phoenix	(d)	1.6	-	-	-	-
Tucson	01/01/90	1.6	1.0	2.5	-	-
California						
Santa Barbara	(d)	1.6	-	2.0	-	2.5
Statewide	01/01/91	1.6	-	-	-	-
Colorado						
Statewide	01/01/90	-	-	-	-	2.5
Delaware River Basin Commission (DE/NY/NJ/PA)	01/01/90	1.6	-	-	-	-
New York						
Statewide	01/01/91	1.6	-	-	-	-
New Paltz	(d)	1.6	-	-	-	-
Rhode Island						
Statewide	(d)	1.6	-	-	-	-
Washington						
Statewide	07/01/91	1.6	1.0	2.5	-	2.5

Source: National Wildlife Federation, "States and Communities with Low Consumption Plumbing Product Regulations," (table dated March 3, 1989 compiled and distributed by the National Wildlife Federation).

(a) Gallons per flush.
(b) Gallons per minute.
(c) The 3/2/89 effective date applies to all two-piece toilets and all floor-mounted flushometer toilets. Effective 3/2/90, the standard applies to all types of toilets.
(d) Not available.

County have incorporated water conservation in local planning processes.[77] Santa Fe, New Mexico, has used performance standards for developments. Denver has provided incentives for water- and energy-efficient new housing.

Water Conservation in Three Cities

A look at three cities (Denver, Colorado; Hyattsville, Maryland; and Jacksonville, Florida) reveals the diversity of local water conservation efforts.[78]

The Denver Water Department promotes voluntary water conservation by users, having explicitly rejected the idea of using rates for this purpose. The city encourages indoor conservation through the use of low-flow plumbing fixtures. Outdoors, the emphasis on conservation is proper soil conditioning, xeriscaping, resetting sprinkler timers during the growing season, and watering lawns according to evapotranspiration (ET) calculations. ET is a measure of the water lost from Denver's "typical bluegrass lawns" from evaporation and transpiration. The ET number is publicized daily by the Denver Water Department during the city's summer lawn-watering season so that homeowners, knowing how much water has been lost from their lawns in the previous 24-hour period, can water only as much as is needed to replace the lost water.

According to the Water Department's Office of Water Conservation, Denver's ET program was mandatory from 1980 to 1983, during which time the city experienced an 11 to 18 percent reduction in summer water usage. Today, like Denver's other water conservation efforts, the ET program is voluntary. The city promotes these volunteer efforts by conducting school education programs, sending water conservation mailings to customers, holding xeriscaping seminars, and displaying demonstration xeriscape garden plots. The Department has no current data on either the effectiveness of the city's voluntary actions in reducing water consumption or on the participation rate of citizens in the various water conservation programs.

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[77] Welford Sanders and Charles Thurow, *Water Conservation in Residential Development: Land-Use Techniques* (Chicago: American Planning Association, 1982), 3.

[78] These case studies were prepared on the basis of telephone interviews.

The Washington Suburban Sanitary Commission of Hyattsville, Maryland has conducted an active water conservation program for over a decade. The conservation measures used by the Commission include:

- Low-flow agreements with other municipalities that use Potomac River reservoirs.
- Water conservation pamphlets and newsletters provided to all customers.
- Distribution of showerhead flow restrictors, of dye pills to check for toilet leaks, and of one-quart bottles to be used in the toilets to displace some of the water used in flushing.
- Sponsoring a waterscaping and landscaping contest to promote reduced outdoor water use.
- Participation in parades and other events.

According to a Commission spokesperson, however, the most effective of all the Commission's water conservation measures is its increasing block rate schedule (or sliding scale) rate schedule for both water and sewer use. This one-hundred-step "conservation-oriented rate schedule" establishes a different rate for every ten gallons of water or sewer use.[79] The Commission spokesperson stated that all of its conservation measures taken together have postponed the need for new treatment facilities into the 1990's, and pointed out the significance of this achievement for an area currently experiencing housing growth that is adding one-thousand connections per month to the Commission's water and sewer system.

The Jacksonville Water Division historically has had low water rates and a decreasing-block rate schedule. The Water Division's sewer rates, however, historically have been high and appear to have stimulated water conservation. Recently, some customers have installed secondary meters to measure the amount of water used outside the house, which does not require wastewater treatment.

At the time of their research, the Water Division was contemplating revising its rate schedule, subject to city council approval. One alternative under consideration was an increasing block rate for water. The Water Division is under the jurisdiction of a water management district that periodically issues consumptive use permits and actively promotes water reuse and conservation measures.

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[79] Washington Suburban Sanitary Commission, *WSSC Pipeline* (January 1978).

The Global Context

Water issues, of course, are not confined to United States borders. The United Nations General Assembly designated the 1980s (1981-1990) as the International Drinking Water Supply and Sanitation Decade to focus attention on worldwide water issues and particularly the problems of developing nations. A global survey by the World Health Organization found that the world's regions do not vary significantly in terms of the constraints to improving water supply and sanitation conditions: "Overriding constraints at the global level include the insufficiency of trained personnel, limitations of funds, shortcomings in operation and maintenance and in logistics and inadequate means to recover from customers the cost of operating the service."[80]

Water shortages happen almost everywhere. One way that the global community has addressed the problem of drought is through the early warning program of the Assessment and Information Services Center (AISC) of the National Oceanic and Atmospheric Administration/National Environmental Satellite, Data and Information Service (NOAA/NESDIS).[81] Since 1979 it has provided climate impact analysis and early warning alerts to national and international agencies that use this information in conducting agricultural assessments and planning relief efforts. The service also aims at improving the early warning capabilities of developing nations.

Proposed diversions of water to the United States from its neighbors to the north and south also epitomize the continental nature of the water issue:

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[80] World Health Organization, *The International Drinking Water Supply and Sanitation Decade: Review of National Baseline Data* (Geneva, Switzerland: World Health Organization, 1984), 15.

[81] Clarence M. Sakamoto and Louis T. Steyaert, "International Drought Early Warning Program of NOAA/NESDIS/AISC," in Wilhite and Easterling, eds., *Planning for Drought*, 247-72.

> Both Canada and Mexico share borders with the United States and across those borders occur common problems of matching water needs with available supply. Yet within the continent of North America, vast quantities of surface water occur, and the developable yield of all of those resources could meet the needs of all three nations for the foreseeable future, *if it were possible to develop, allocate, manage, and use the water in the common interest.* Realistically, the difficulty of this coordination, while not insurmountable, is awesome, particularly as regards the political/ legal/institutional/financial aspects. Within our own United States, discussions of interbasin transfers of water within a state or between and among states are generally conducted with a great deal more heat than light, and often with extraordinarily slow results.[82]

At a purely conceptual level, proposed international diversion projects thus far include the Rocky Mountain Plan, the North American Water and Power Alliance, the Western States Augmentation Concept, and the (unofficial) Canadian Proposal.[83] Using systems of canals and reservoirs, some of these projects envision water uses other than supply, namely navigation and hydroelectric power generation. Although there is a potential for importing water to the mutual benefit of the nations and river basins involved, the price tag of each project is high; in some proposals it amounts to hundreds of billions of dollars. Further, the barriers to implementation may be nearly insurmountable because the already familiar politics of interbasin transfers would be overlaid with international politics, including potentially complex treaty negotiations.

Water and the Policy Agenda

Elevating water issues on the national policy agenda has been the goal of some groups. In 1987, the League of Women Voters published *Safety on Tap* and in 1988 the National Wildlife Federation published *Danger on Tap*, both of which focused on drinking water assessments and federal standards.[84] In 1988, the National Water Alliance issued a policy paper to the presidential candidates urging them to state their positions on such issues as groundwater protection and management, wetlands and coastal erosion, water supply (drinking water), surface water quality (wastewater treatment), water resources, and infrastructure finance.[85] In 1989, the Harvard Energy and Environmental Policy Center issued a review of federal water policy outlining an agenda for action.[86]

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[82] Harvey O. Banks, Jean O. Williams, and Joe B. Harris, "Developing New Water Supplies, in Engelbert and Scheuring, eds., *Water Scarcity*, 110.
[83] Ibid.

Institutional issues seem to dominate the policy agenda for water and come in all shapes and sizes. Many scholars take time to itemize the contemporary problems they see as most troublesome, as in the following list adapted from a water supply textbook:[87]

- The nonuniformity and sometimes conflicting nature of state and federal water laws.
- The failure of laws, agencies, and water users to recognize the interrelationships of surface waters and groundwaters and the need for their coordinated use.
- The statutory and administrative separation of water quality and water quantity issues when, in fact, the two are intertwined.
- The failure to recognize that water is not a free good.
- The focus on individual water projects as opposed to comprehensive water resource goals.
- The lack of effective national, state, and regional mechanisms for setting priorities for water resource development.
- The lack of mechanisms for ensuring that water resource plans are implemented.

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[84] League of Women Voters Education Fund, *Safety on Tap: A Citizen's Drinking Water Handbook* (Washington, DC: League of Women Voters Education Fund, 1987); and Norman L. Dean, *Danger on Tap: The Government's Failure to Enforce the Federal Safe Drinking Water Act* (Washington, DC: National Wildlife Federation, 1988).

[85] National Water Alliance, *Water Issues for the Next Decade* (Washington, DC: National Water Alliance, 1988).

[86] Foster and Rogers, *Federal Water Policy*.

[87] Adapted from Warren Viessman, Jr. and Mark J. Hammer, *Water Supply and Pollution Control* (Cambridge, MA: Harper & Row, 1985, Fourth Edition), 7-8.

- The multiplicity of jurisdictions over water within the different levels of government.
- The inability of federal, state, and local agencies to coordinate their programs.
- The proliferation of regulations, some of which constrain rather than promote the effective use of the nation's waters.

Water Resource Policy Reform

The growing interest in water supply issues, particularly the institutional barriers to forming an effective national policy, has motivated several analysts to recommend reforms. Foster and Rogers recommend seven initiatives for improving federal water supply policy:[88]

- Create a President's Water Council.
- Form regional councils in the key water-problem regions.
- Develop a water information program in advance of crisis.
- Renew the national water resources research program.
- Accelerate educational efforts, including regional forums.
- Investigate such areas as western water rights and water quality.
- Explore the application of marketing and pricing techniques for federal water and the creation of a trust fund for financing federal water programs.

Many policy proposals view drought planning as central to water supply planning. In fact, drought planning could have a positive impact on water resources planning at all government levels because it heightens the awareness of impending supply issues. The potential for drought planning is great because so little of it has been accomplished in the past. Thus, it is an ideal area for policy reform.

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[88] Foster and Rogers, *Federal Water Policy*, i-ii.

Donald A. Wilhite provides a blueprint for drought planning that could be used by governmental agencies:[89]

- A monitoring/early warning system to provide decision-makers at all levels with information about the onset, continuation, and termination of drought conditions and their severity.
- Operational assessment programs to determine--reliably--the likely impact of the drought.
- An institutional structure for coordinating governmental actions, including information flow within and between levels of government, and drought declaration and revocation criteria.
- Appropriate drought assistance programs with predetermined eligibility and implementation criteria.
- Financial resources to maintain operational programs and to initiate research required to support drought assessment and response activities.
- Educational programs designed to promote the adoption of appropriate drought mitigation strategies among the various economic sectors most affected by drought.

Finally, it is increasingly apparent that water conservation will have a role in future governmental policy in the water supply area. A study by the Congressional Research Service identified several mechanisms that could be used to alter patterns of water supply and use and promote conservation at the national level:[90]

- Implement conservation programs and give agencies sufficient authority to see that they are enforced.
- Regulate fuel and energy costs for agricultural and industrial production.
- Place restrictions on grant and loan programs that require that new facilities be constructed and operated to maximize water use (efficiency).

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[89] Wilhite, "The Role of Government in Planning for Drought" in Wilhite and Easterling, eds., *Planning for Drought*, 439.
[90] Viessman and DeMoncada, *State and National Water Use Trends*, 296.

- Impose environmental regulations such as limitations on thermal discharges. This would encourage shifts away from "once-through-cooling," for example.
- Initiate educational programs at school and community levels to instill in citizens a more conservation-oriented approach to water use.
- Encourage reuse and recycling of water by all sectors.
- Limit funding for construction of new water resources development facilities.
- Develop and market more efficient devices for using water in homes and industries.
- Employ pricing policies, taxes, and incentives to encourage greater water-use efficiency.

There is no divining rod pointing out the ultimate solution to the nation's water problems. Future water policy in the areas of water supply, drought, and conservation may depend largely on reform and radicalization of certain key institutions. It will also require a shift away from crisis management to risk management and, perhaps, a more consensual decisionmaking process that includes water suppliers and members of the public as well as the various governmental agencies that make water policy. It will also require planning. Even with exceptional planning and preparation, crisis situations arise. These may call for a certain degree of regulatory flexibility. Regulators of water quality, quantity, and price may all have to be flexible in dealing with the demands of a water crisis. The states have primacy in many facets of water resource policy. As regulators of water utilities, the state public utility commissions will continue to play an important institutional part in designing tomorrow's water policies. This includes traditional ratemaking as well as emerging regulatory roles, such as integrated water resource planning.

The fragmented and pluralistic nature of United States water policy today is not well suited to the demands of contemporary water problems, particularly scarcity. Not only is existing water policy often inefficient, it is sometimes ineffective, especially in identifying priorities and appropriate roles for governmental and private players. Moreover, the many layers of government involved may also undermine the public's faith in the management of the nation's water resources. Above all, it has become apparent that institutional reform is essential to the design of better water resource policy. As accessible, affordable water becomes scarce, better policy at all government levels may be essential to averting a tragedy of the water commons.

APPENDIX A

COMPARATIVE STATE DATA ON WATER WITHDRAWALS AND CONSUMPTION

TABLE A-1

USE OF OFFSTREAM FRESH AND SALINE WATER WITHDRAWALS BY STATE IN MILLIONS OF GALLONS DAILY FOR 1985

State	Freshwater						Saline
	Public Supply	Domestic and Commercial	Irrigation and Livestock	Industrial and Mining	Thermo-electric	Total	Total
Alabama	615	42	165	848	6,920	8,590	3
Alaska	76	10	156	133	30	406	0
Arizona	618	44	5,581	125	53	6,420	13
Arkansas	257	68	4,310	175	1,090	5,910	0
California	5,310	193	30,799	596	480	37,400	12,300
Colorado	737	25	12,461	179	110	13,500	32
Connecticut	362	48	11	79	700	1,200	2,580
Delaware	77	12	29	19	1	138	1,520
D.C.	218	0	0	0	130	348	0
Florida	1,680	315	2,976	652	651	6,280	10,700
Georgia	836	127	500	625	3,280	5,370	77
Hawaii	204	44	910	20	90	1,270	880
Idaho	212	105	21,640	334	0	2,230	0
Illinois	1,780	237	128	601	11,700	14,400	38
Indiana	575	140	95	2,751	4,480	8,030	0
Iowa	350	103	239	260	1,810	2,770	0
Kansas	316	42	4,798	95	415	5,670	0
Kentucky	404	63	58	266	3,410	4,200	0
Louisiana	629	46	1,683	2,092	5,470	9,920	505
Maine	108	57	31	219	432	848	673
Maryland	771	88	57	95	399	1,410	5,300
Massachusetts	767	273	17	131	5,070	6,260	3,400
Michigan	1,250	157	235	1,380	8,390	11,400	5
Minnesota	473	157	272	457	1,470	2,830	0
Mississippi	312	20	1,271	231	479	2,310	197
Missouri	645	71	347	116	4,930	6,110	0
Montana	158	16	8,350	60	67	8,650	0
Nebraska	248	24	7,390	167	2,210	10,000	0
Nevada	288	19	3,376	32	23	3,740	3
New Hampshire	89	22	2	239	336	687	207

TABLE A-1--Continued

	Freshwater						Saline
State	Public Supply	Domestic and Commercial	Irrigation and Livestock	Industrial and Mining	Thermo-electric	Total	Total
New Jersey	1,050	79	135	336	726	2,320	4,620
New Mexico	226	45	2,870	83	59	3,280	0
New York	2,860	321	58	1,080	4,720	9,040	6,150
North Carolina	595	192	166	533	6,400	7,890	872
North Dakota	69	15	176	13	892	1,160	0
Ohio	1,420	190	58	540	10,500	12,700	0
Oklahoma	521	58	450	113	134	1,270	0
Oregon	416	82	5,735	301	12	6,540	0
Pennsylvania	1,600	211	81	2,208	10,200	14,300	0
Rhode Island	116	6	6	20	0	148	261
South Carolina	359	103	44	1,135	5,180	6,810	6
South Dakota	80	33	507	49	4	675	0
Tennessee	627	75	74	1,613	6,060	8,450	0
Texas	2,990	130	8,381	1,104	7,460	20,100	5,210
Utah	447	7	3,628	84	24	4,180	133
Vermont	53	12	6	55	1	126	0
Virginia	579	134	105	592	3,460	4,870	2,380
Washington	955	118	4,970	522	427	7,000	37
West Virginia	151	22	30	1,028	4,210	5,440	0
Wisconsin	575	88	174	461	5,440	6,740	0
Wyoming	98	30	5,676	161	236	6,200	23
Puerto Rico	391	18	166	18	5	598	2,000
Virgin Islands	5	3	0	0	0	7	117
Total	36,500	4,550	141,470	24,970	131,000	338,000	60,300

Source: Wayne B. Solley, Charles F. Merk, and Robert R. Pierce, *Estimated Use of Water in the United States* (Washington, DC: U.S. Geoglogical Survey, 1988), 63. Some figures may be affected by rounding. For uses other than public supply, figures represent self-supplied water only. Total saline water combines industrial, mining, and thermoelectric uses.

TABLE A-2

PUBLIC SUPPLY OF FRESHWATER BY STATE: POPULATION SERVED, WATER WITHDRAWALS, AND PER CAPITA USE FOR 1985

	Population served in thousands			Water withdrawals in million gallons daily			Per capita use in gallons per day
	Source			Source			
State	Ground water	Surface water	Total	Ground water	Surface water	Total	
Alabama	1,240	2,270	3,510	173	442	615	175
Alaska	231	117	348	41	35	76	217
Arizona	1,930	1,160	3,090	385	233	618	200
Arkansas	801	880	1,680	101	156	257	153
California	16,300	8,000	24,300	3,730	1,570	5,310	218
Colorado	447	2,560	3,010	86	651	737	245
Connecticut	518	2,170	2,680	66	296	362	135
Delaware	274	240	514	29	49	77	151
D.C.	0	626	626	0	218	218	348
Florida	8,680	1,060	9,740	1,490	185	1,680	172
Georgia	1,460	3,200	4,660	205	631	836	179
Hawaii	1,050	80	1,130	172	31	204	181
Idaho	611	92	704	185	27	212	302
Illinois	3,850	5,980	9,830	467	1,320	1,780	181
Indiana	1,790	1,880	3,670	271	304	575	157
Iowa	1,570	557	2,130	259	92	350	164
Kansas	994	1,000	2,000	158	158	316	158
Kentucky	309	2,460	2,770	49	356	404	146
Louisiana	1,960	1,940	3,900	276	352	629	161
Maine	216	613	829	24	84	108	130
Maryland	619	2,950	3,560	70	702	771	216
Massachusetts	1,610	3,720	5,330	181	586	767	144
Michigan	1,400	5,970	7,370	222	1,030	1,250	170
Minnesota	1,850	848	2,700	265	208	473	175
Mississippi	2,070	189	2,260	275	37	312	138
Missouri	1,470	2,670	4,140	171	474	645	156
Montana	228	386	614	62	96	158	257
Nebraska	1,170	159	1,320	208	39	248	187
Nevada	303	579	882	94	193	288	326
New Hampshire	208	429	637	28	61	89	139

TABLE A-2--Continued

State	Population served in thousands			Water withdrawals in million gallons daily			Per capita use in gallons per day
	Source			Source			
	Ground water	Surface water	Total	Ground water	Surface water	Total	
New Jersey	2,850	3,860	6,710	406	641	1,050	156
New Mexico	857	147	1,000	198	28	226	225
New York	4,170	11,700	15,900	535	2,330	2,860	180
North Carolina	803	2,650	3,450	88	507	595	172
North Dakota	256	256	512	30	39	69	135
Ohio	2,840	6,060	8,900	395	1,020	1,420	159
Oklahoma	690	2,140	2,830	106	414	521	184
Oregon	418	1,520	1,940	83	332	416	214
Pennsylvania	1,320	6,850	8,170	258	1,340	1,600	196
Rhode Island	152	732	884	15	101	116	132
South Carolina	614	1,910	2,520	76	283	359	142
South Dakota	431	117	548	65	16	80	147
Tennessee	1,340	2,320	3,660	243	384	627	172
Texas	6,890	8,510	15,400	1,230	1,760	2,990	194
Utah	1,020	553	1,570	299	148	447	285
Vermont	106	237	343	17	36	53	154
Virginia	598	3,620	4,210	75	504	579	137
Washington	1,480	2,040	3,530	339	616	955	271
West Virginia	363	947	1,310	37	114	151	115
Wisconsin	1,700	1,430	3,130	275	301	575	184
Wyoming	146	183	329	48	50	98	298
Puerto Rico	544	2,390	2,930	84	307	391	133
Virgin Islands	4	44	47	0	4	5	95
Total	84,800	115,000	200,000	14,600	21,900	36,500	183

Source: Wayne B. Solley, Charles F. Merk, and Robert R. Pierce, *Estimated Use of Water in the United States* (Washington, DC: U.S. Geological Survey, 1988), 13. Some figures may be affected by rounding.

TABLE A-3

PUBLIC SUPPLY OF FRESHWATER BY STATE: WATER DELIVERIES BY TYPE OF USE

State	Domestic	Commercial	Industrial	Thermoelectric power	Public use and losses	Total withdrawals
Alabama	332.0	61.0	221.0	.0	.0	615
Alaska	30.0	31.0	7.8	.3	7.6	76
Arizona	449.0	90.0	79.0	.0	.0	618
Arkansas	170.0	87.0	.1	.3	.0	257
California	3,240.0	1,220.0	494.0	31.0	325.0	5,310
Colorado	456.0	112.0	18.0	13.0	138.0	737
Connecticut	178.0	49.0	62.0	1.3	72.0	362
Delaware	36.0	12.0	18.0	.6	11.0	77
D.C.	174.0	44.0	.0	.0	.0	218
Florida	1,200.0	248.0	142.0	4.8	84.0	1,680
Georgia	545.0	142.0	135.0	.0	14.0	836
Hawaii	132.0	51.0	6.4	.0	15.0	204
Idaho	200.0	6.1	6.7	.0	.0	212
Illinois	850.0	471.0	255.0	.9	206.0	1,780
Indiana	423.0	78.0	73.0	.0	.8	575
Iowa	289.0	4.2	41.0	1.6	14.0	350
Kansas	150.0	83.0	41.0	1.0	41.0	316
Kentucky	179.0	19.0	167.0	.0	40.0	404
Louisiana	564.0	7.6	1.5	.0	55.0	629
Maine	96.0	1.7	11.0	.0	.2	108
Maryland	365.0	57.0	55.0	.0	294.0	771
Massachusetts	415.0	276.0	69.0	4.2	3.1	767
Michigan	630.0	339.0	247.0	.0	36.0	1,250
Minnesota	401.0	23.0	46.0	1.5	1.5	473
Mississippi	165.0	47.0	28.0	1.5	71.0	312
Missouri	355.0	60.0	133.0	.3	97.0	645
Montana	90.0	29.0	1.2	.0	38.0	158
Nebraska	149.0	50.0	49.0	.0	.0	248
Nevada	189.0	54.0	6.3	2.4	36.0	288
New Hampshire	63.0	9.1	16.0	.0	.0	89

TABLE A-3--Continued

State	Domestic	Commercial	Industrial	Thermoelectric power	Public use and losses	Total withdrawals
New Jersey	503.0	136.0	240.0	.6	167.0	1,050
New Mexico	179.0	42.0	2.8	.0	2.8	226
New York	1,470.0	282.0	1,010.0	.0	95.0	2,860
North Carolina	315.0	137.0	128.0	.0	17.0	595
North Dakota	40.0	14.0	2.3	.0	13.0	69
Ohio	467.0	326.0	340.0	.3	283.0	1,420
Oklahoma	158.0	58.0	204.0	2.2	98.0	521
Oregon	246.0	45.0	53.0	.0	72.0	416
Pennsylvania	539.0	186.0	246.0	.0	629.0	1,600
Rhode Island	59.0	15.0	20.0	.0	23.0	116
South Carolina	189.0	5.7	86.0	.0	79.0	359
South Dakota	61.0	14.0	5.4	.0	.0	80
Tennessee	303.0	163.0	98.0	.6	63.0	627
Texas	2,200.0	105.0	284.0	23.0	373.0	2,990
Utah	340.0	50.0	15.0	.0	43.0	447
Vermont	34.0	5.2	13.0	.0	.0	53
Virginia	337.0	70.0	57.0	.0	115.0	579
Washington	516.0	133.0	306.0	.0	.0	955
West Virginia	81.0	21.0	22.0	.0	27.0	151
Wisconsin	169.0	98.0	153.0	.2	155.0	575
Wyoming	61.0	14.0	3.2	1.9	18.0	98
Puerto Rico	178.0	30.0	12.0	1.4	170.0	391
Virgin Islands	2.1	.2	.0	.7	1.5	5
Total	21,000.0	5,710.0	5,730.0	96.0	4,040.0	36,500

Source: Wayne B. Solley, Charles F. Merk, and Robert R. Pierce, *Estimated Use of Water in the United States* (Washington, DC: U.S. Geoglogical Survey, 1988), 13. Some figures may be affected by rounding. Public use and losses includes transfers from adjacent areas.

TABLE A-4

TOTAL WATER WITHDRAWALS AND CONSUMPTION FOR BASE YEAR 1975 AND PROJECTED FOR THE YEAR 2000

State	Total Withdrawals in Million Gallons Per Day		Percent Change	Total Consumption in Million Gallons Per Day		Percent Change
	1975	2000		1975	2000	
Alabama	6,433	6,120	-5%	341	1,264	271%
Alaska	342	776	127	67	459	585
Arizona	8,509	7,382	-13	4,314	4,253	-1
Arkansas	3,376	3,747	11	1,704	2,293	35
California	39,082	40,786	4	26,101	29,158	12
Colorado	12,625	11,877	-6	5,410	5,991	11
Connecticut	1,634	656	-60	177	307	73
Delaware	775	514	-34	68	127	87
D.C.	261	400	53	22	23	5
Florida	7,304	10,313	41	3,102	4,750	53
Georgia	4,336	3,787	-13	449	1,378	207
Hawaii	1,903	1,340	-30	572	661	16
Idaho	19,865	14,842	-25	5,034	5,742	14
Illinois	12,538	6,706	-47	739	1,709	131
Indiana	11,779	3,463	-71	625	1,494	139
Iowa	2,212	1,855	-16	265	559	111
Kansas	5,234	5,705	9	2,839	3,539	25
Kentucky	3,575	3,802	6	296	776	162
Louisiana	9,561	10,091	6	2,158	2,799	30
Maine	852	487	-43	102	298	192
Maryland	1,627	1,382	-15	164	455	177
Massachusetts	1,503	1,140	-24	127	270	113
Michigan	11,885	4,469	-62	811	1,521	88
Minnesota	2,602	2,080	-20	358	857	139
Mississippi	1,431	11,110	676	452	810	79
Missouri	4,978	3,559	-29	422	873	107
Montana	9,649	13,817	43	2,952	4,903	66
Nebraska	11,471	11,671	2	6,115	7,031	15
Nevada	3,286	3,250	-1	1,814	2,030	12
New Hampshire	374	317	-15	26	73	181

TABLE A-4--Continued

State	Total Withdrawals in Million Gallons Per Day 1975	Total Withdrawals in Million Gallons Per Day 2000	Percent Change	Total Consumption in Million Gallons Per Day 1975	Total Consumption in Million Gallons Per Day 2000	Percent Change
New Jersey	2,679	2,053	-23	435	739	70
New Mexico	4,200	3,652	-13	2,646	2,321	-12
New York	8,603	14,061	63	987	1,432	45
North Carolina	4,442	7,183	62	370	1,165	215
North Dakota	648	2,094	223	228	562	146
Ohio	16,860	8,064	-52	886	1,888	113
Oklahoma	2,048	2,483	21	1,246	1,529	23
Oregon	9,141	9,266	1	3,226	4,248	32
Pennsylvania	13,698	6,678	-51	920	1,985	116
Rhode Island	154	113	-27	14	25	79
South Carolina	3,522	2,565	-27	201	770	283
South Dakota	641	1,009	57	380	756	99
Tennessee	7,301	4,912	-33	295	1,094	271
Texas	22,979	21,368	-7	15,896	15,137	-5
Utah	5,445	4,872	-11	2,049	2,177	6
Vermont	203	200	-1	29	80	176
Virginia	3,387	2,850	-16	311	877	182
Washington	7,992	8,744	9	3,538	4,785	35
West Virginia	5,525	1,651	-70	246	653	165
Wisconsin	5,794	2,471	-57	347	866	150
Wyoming	9,040	9,875	9	2,804	3,521	26
Total*	335,306	303,606	-9	104,677	133,015	27

Source: Oak Ridge National Laboratory, *State Water Use and Socioeconomic Data Related to the Second National Water Assessment* (Oak Ridge, Tennessee: Oak Ridge National Laboratory, 1980), B-2.

* Figures may not add to totals because of independent rounding.

APPENDIX B

WATER CONSERVATION MEASURES

WATER CONSERVATION MEASURES

Retrofitting with Low-Flow Devices

- Distribute retrofit kits consisting of flow-restricting devices for showerheads, faucets, and toilets at no or low cost.
- Require all new construction and renovation to have low-flow fixtures that meet water conservation plumbing code requirements.
- Require low-flow devices to be installed in all state university systems, government buildings, and government-assisted institutions.
- Require low-flow devices to be installed prior to closing home mortgages.
- Require that only low-consumptive appliances and plumbing fixtures be sold within state boundaries.
- Require public health inspectors, state auditors, and home appraisers to demonstrate installation of flow devices upon inspection visit.
- Encourage state plumbing associations to have plumbers demonstrate and promote installation of low-flow devices in service calls.

Metering

- Meter all unmetered areas or institute a study of long-range benefits of metering unmetered areas.
- Require all new or renovated construction to be metered.
- Require all government buildings/installations to be metered.
- Require all projects with government assistance/grants to be metered.
- Offer technical/financial assistance or tax incentives to low-income water users desiring to become metered.
- Offer technical/financial assistance or tax incentives to unmetered institutions, buildings, facilities for the purpose of becoming metered.

Plumbing Code Changes

- Require all new or renovated construction to meet new fixture standards.
- Install sinks with aerators or spray taps.
- Install lavatory sinks in nondwelling units with self-closing valves.
- All new automatic lawn sprinklers should meet water conservation standards.
- Hot water pipes should be fully insulated.
- Appliances should meet both energy and water saving standards.

Leak Detection and Repair

- Use special trucks with sonar devices to detect leaks.
- Implement a study on the benefits of leak detection and repair in regions where this is not practiced.
- Institute a state leak detection inspection agency which has the authority to require municipalities to repair all leaks for which the savings in water exceeds the savings in cost.
- Require all government buildings and government-assisted institutions to practice leak detection and repair.
- Promote community education programs for building owners and managers and public/private swimming pool managers on leak detection.
- Require tamper-proof locking fire hydrant caps in inner city residential areas; use spray bars for summer recreation with hydrants.

Public Education/Information Programs

- Institute a state public education program with at least one full-time salaried employee.
- Set public water conservation goals.
- Develop an intensified media program using all forms of media.
- Make available and distribute literature concerning water conservation devices, water reuse, leak detection/repair, low water consumptive appliances, and low-water-use shrubs and grasses.
- Promote water conservation with bill inserts listing conservation tips.
- Develop a water bill that points our increases/decreases in monthly use.
- Educate water agency phone staffs on water conservation, especially during a drought; provide a water conservation fact sheet for reference.
- Encourage utilities to provide the public with a home auditor who can inspect and advise private dwellers as well as municipalities on water conservation savings.
- Develop citizen involvement through a coalition of public interest and ecology groups.
- Create a speakers' bureau on water conservation to make presentations to schools, businesses, and service organizations and to appear on television and speak on radio.
- Produce or obtain a water conservation film or slide show for public showings, speaking engagements, municipal cafeterias, and for television and movie theater fillers.
- Promote water conservation conferences, symposia, and seminars.
- Encourage boards of education and teachers to become involved in water conservation through classroom lectures and incentives for children to conduct home checks.
- Develop public demonstration models of water conservation measures using model homes, mobile home/vehicle displays, and university programs.
- Put water conservation displays, literature, and posters in public places.
- Set up joint venture public demonstration projects with energy conservation agencies, schools, public interest groups, and businesses.
- Develop a rating system to be fixed to plumbing fixtures/appliances for consumer comparison.
- Promote awareness with a "camel day," "camel week," or water conservation week, in which people try to cut down on water use.
- Encourage restaurants to display tent cards explaining how much water is used in icing, filling, and cleaning a water glass.
- Promote a poster or essay contest for the best water conservation ideas.
- Distribute a water conservation newsletter to noncustomer consumers, such as apartment dwellers.
- Contact and recruit local college help for resources and ideas; require land grant colleges to develop model programs within their facilities.
- Promote neighborhood captains who can go door-to-door or hold neighborhood discussions on water conservation.

Rate Structure/Billing Practices

- Change rate structure from a decreasing block or flat rate to an increasing block rate with various stages and levels accounting for season, industry, necessity, and peak period.
- Use a proven model for designing an increasing block rate.
- Translate water bills into layman's terms.
- Require water bills to cover either a monthly or quarterly calendar period with no overlapping time periods.
- Require water bills to break down the consumption record on a monthly basis if quarterly billing is used,
- Require water bills to state the current cost of water per unit, the previous bill consumption rate and cost, any increase/decrease from the previous bill, current monthly consumption rate, water conservation tips, and a water conservation hotline number.

Drought Contingency Planning

- An emergency state plan should be outlined and ready for implementation when certain critical levels in the supply system are reached.
- A high-intensity-communication program is paramount.
- Sample plans are available.

Reuse and Recycling

- Institute study on the benefits of water reuse pilot plants.
- Require all unrecycled air conditioning units to convert either to a dry-cooled or a recycling unit within a set period of time.
- Require car washes to filter and reuse water.
- Require all new parks/golf courses to be constructed to irrigate with treated effluent.

Outdoor Use

- Distribute literature to nurseries, landscapers, garden centers, and lawn services concerning outdoor water conservation.
- Encourage nurseries/landscapers to recommend low-water consumptive shrubbery and vegetation.
- Restrict the size of lawn areas around new construction in water-short regions and encourage use of native, drought-resistant vegetation in landscaping.
- Restrict domestic lawn watering to nonpeak, nonevaporative hours, or develop alternate regional or alternate daytime lawn watering schedules.
- Require all new automatic sprinklers to meet water conservation requirements.
- Encourage motor vehicle washing during nonpeak periods.
- Discourage or ban driveway/sidewalk washing.
- Require all car washes to convert to a recycling system.

Groundwater Management

- Establish a state groundwater board with permit and review authority for groundwater withdrawals.
- Require water conservation practices, limits on depth of wells, recharge program for excess wastewater, and industrial recycling procedures as a part of permits.
- Inventory groundwater resources.
- Determine the sequencing of new wells to alleviate drought on a short-term basis.
- Examine the potential of conjunctive management of surface water and groundwater so that in periods of heavy runoff, aquifers may be recharged and in periods of drought more reliance may be made on groundwater sources and less on surface water sources.

Irrigation Use

- Examine the potential of modern irrigation scheduling.
- Check the efficiency of the irrigation system (i.e., leaks and debris).
- Maintain irrigation systems to prevent runoff, ponding, too slow or too rapid movement, erosion, salt deposits, and distribution losses.
- Check the potential efficiency from laser land leveling.
- Inspect sprinkler system couplings for hardened or leaky gaskets.
- Compute water delivery requirements based on evaporation rates, plant water requirements, leaching requirements, precipitation, seepage, and runoff.
- Schedule irrigations according to soil moisture levels.
- Make use of a tensionmeter to test how well roots are extracting water.
- Install devices to measure water use and keep records for scheduling.
- Use flowmeters on wells/pipes to prevent overwatering and aid scheduling.
- Use a feel test to help determine when to irrigate (i.e., when coarse or medium soil is sticky but will not form a ball and where fine soil is pliable).
- Limit water applications so that water does not seep below the root zone.
- Avoid sprinkling during periods of high wind and temperature.
- Add fertilizer and pesticides during center-pivot operations.
- Keep soil moisture deficits as uniform as possible and reduce the sensitivity of the crop to drought through conditioning.
- Irrigate more lightly later in the season to let crops "mine" soil water.
- Extend intervals between irrigations to reduce evaporation.
- Do not fill soil moisture capacity in climates where rain may cause runoff.
- Irrigate in the fall if water is available for storing water in the soil.
- Irrigate early in the spring,if the soil is not saturated to store water in the soil, but avoid overirrigation that wastes water to deep seepage.
- Spring irrigate hay and pasture crops as soon as the ground thaws, but not corn unless the ground is dry to a three-foot depth.
- Follow the critical water-need periods for different crops.
- Consider alternative crops that require less water.
- Grow high-value crops in areas of high water abundance to reduce risk and the need to have water available in high risk (drought) areas.

Irrigation Use (continued)

- Plant crop hybrids best adapted to the growing season and water supply.
- Explore alternative irrigation methods such as drip irrigation.
- Where legal, collect and reuse water normally lost in irrigation runoff.
- Keep fruit trees adequately watered during the period they are most sensitive to moisture deficiencies because of root growth.
- Water top priority perennial crops and orchards during drought.
- Remember that older trees have deeper roots and can probably survive longer during periods of drought than younger trees.
- Water trees only on one side during severe droughts.
- Reduce seepage losses by diverting silty water; removing areas of very porous earth; using firm plastic, rubber sheeting, or sprayed asphalt; or using buried concrete pipe for conveyance.

Industrial Use

- Recycling and reuse of cooling and process water.
- Pressure reducing valves.
- Increased efficiency of application of process water.
- Use of the wastewater from one product as process water for another product.
- Leak detection and repair.
- Use of all techniques of residential water conservation to reduce water use by employees in toilets, sinks, and showers.
- Modification of process to reduce or eliminate water use.
- Reduction of "drag-out" to reduce amount of rinsing water required.
- Substitution of salt or brackish water for freshwater.

Source: Adapted from Brent Blackwelder and Peter Carlson, *Survey of the Water Conservation Programs in the Fifty States: Model Water Conservation Program for the Nation* (Washington, DC: Bureau of Reclamation, U.S. Department of the Interior, 1982), 22-28, 66-67, and 89-93.

APPENDIX C

FEDERAL OFFICES AND INTERSTATE AGENCIES AFFECTING WATER RESOURCE POLICY

FEDERAL OFFICES AFFECTING WATER RESOURCE POLICY

LEGISLATIVE OFFICES

United States Congress

Congressional Committees. These carry out most of the work of preparing and considering national legislation. Standing committees of the House of Representatives include committees on agriculture; energy and commerce; interior and insular affairs; merchant marine and fisheries; and science, space and technology. Standing committees of the Senate include agriculture, nutrition, and forestry; commerce, science, and transportation; energy and natural resources; and environment and public works.

General Accounting Office. The investigative arm of Congress charged with examining all matters relating to the receipt and disbursement of public funds. GAO staff respond to requests from committee chairmen, ranking minority committee members, and individual members of Congress when possible. GAO examines parts of virtually every federal program, activity, and function. Staff members concentrate on specific subject areas, enabling them to develop a detailed level of knowledge. GAO studies emphasize compliance with laws and regulations, elimination of wasteful spending, legal and accurate accounting, program effectiveness, cost control, and the analysis of emerging issues of importance to Congress.

Library of Congress. The national library of the United States offering diverse materials for research. The Congressional Research Service (CRS) within the library functions exclusively for the legislative branch. Members of Congress may direct CRS staff to conduct research in any area of policy.

Office of Technology Assessment. The congressional office providing expert, comprehensive, and objective analyses of major public policy issues related to scientific and technological change. The office works closely with congressional and committee staff members, helps resolve uncertainties and conflicting claims, identifies policy options, and alerts Congress to new developments that may affect future federal policy.

EXECUTIVE OFFICES

Executive Office of the President

Council on Environmental Quality. Formulates and recommends national policies to promote the improvement of the quality of the environment. Analyzes changes and trends in the national environment. Reviews and appraises federal programs to determine their contribution to sound environmental policy. Conducts studies, research and analyses relating to ecological systems and environmental quality. Assists president in preparation of the annual environmental quality report to the Congress. Oversees implementation of the National Environmental Policy Act.

Office of Science and Technology Policy. Advises the president of scientific and technological considerations involved in areas of national concern, including the economy, health, foreign relations, and the environment. Evaluates the scale, quality, and effectiveness of the federal effort in science and technology. Assist the president in providing leadership and coordination for the research and development programs of the federal government.

Department of Agriculture

Agricultural Research Service. Administers fundamental and applied research, including research in plant protection and production, and the conservation and improvement of soil, water, and air. Research is conducted at 138 domestic and eight foreign locations, often in cooperation with state partners in universities and experimental stations, with other federal agencies, or with private organizations.

Agricultural Stabilization and Conservation Service. Administers commodity and related land use programs, including:

- The Conservation Reserve Program. Conserves and improves soil and water resources on highly erodible cropland through an up-to-80% cost sharing program with farmers to carry out needed conservation and environmental measures.

- The Water Bank Program. Administers a program through which owners of eligible wetlands in important migratory waterfowl nesting, breeding, and feeding areas can enter into ten-year agreements with the department and receive annual payments for preventing the loss of and preserving, restoring, and improving these areas.

- The Rural Clean Water Program. An experimental program that allows for three- to ten-year contracts between participants and the department to provide cost-sharing of up to 75 percent and technical assistance for the installation of nonpoint source pollution control measures and improvement of water quality in rural America.

Cooperative State Research Service. Administers the congressional acts that authorize Federal funding for agricultural research to the State agricultural experiment stations of the 50 States and Puerto Rico, Guam, the Virgin Islands, American Samoa, Micronesia, the Northern Marianas, and the District of Columbia; approved schools of forestry; the 18[illegible] land-grant institutions and Tuskegee University; colleges of veterinary medicine; and other eligible institutions. Grants include monies for researching specific problems in agriculture, alternative crops, low-input agriculture, aquaculture, and small farms.

Economic Research Service. Produces social science information as a service to the general public and to assist Congress and the administration in developing, administering and evaluating agricultural and rural policies and programs. Research topics include United States and world agricultural production and demand for production resources, and the effects of governmental policies and programs on farmers, rural residents and communities, and natural resources.

Extension Service. The educational agency of the USDA. Acts as the Federal partner in the Cooperative Extension System, a nationwide educational network that links research, science, and technology to the individual needs of people. Within this system, works with State partners comprised of land-grant universities and Tuskegee University, and with local partners comprised of the many different county extension offices. Involved in adapting and tranferring science and technology, and in educating people regarding critical national issues that affect the nation's food sources or agricultural systems.

Farmers Home Administration (FmHA). Provides credit for rural Americans who are unable to get credit from other sources at reasonable rates and terms. Its loan programs include:

- Soil and Water Conservation Loans. FmHA or lenders with an FmHA guarantee make loans to owners or operators of farms and ranches to assist in developing, conserving, and making proper use of their land and other resources.

- Watershed Protection and Flood Prevention Loans. Assist local organizations approved by the Soil Conservation Service in financing projects that protect and develop land and water resources in small watersheds.

- Resource Conservation and Development Loans. Assist in financing projects for natural resource conservation and development in designated areas.

- Community Facility Loans. Loans to quasi-public bodies, nonprofit associations, and certain Indian tribes to finance essential community facilities, including water and waste disposal systems, and necessary related equipment. Water and waste disposal projects may serve residents of open country and rural towns of not more than 10,000 people. Grants for water and waste disposal projects may also be made when necessary to bring user cost to a reasonable level.

Forest Service. Manages the country's 156 national forests, 19 national grasslands, and 15 land utilization projects under the principles of multiple-use and sustained yield, in an effort to balance the need for wood with the other natural benefits that national forests and grasslands provide. Provides national leadership and financial and technical assistance to non-Federal forest landowners, operators, processors of forest products, and urban forestry interests. Carries out cooperative State and private forestry programs through work with the State forester or other State official. Conducts basic forestry research, often in cooperation with State agricultural colleges.

Soil Conservation Service. Develops and carries out a national soil and water conservation program in cooperation with landowners, land operators, other land users and developers, community planning agencies, regional resource groups, and other federal, state, and local government agencies. Also assists in agricultural pollution control, environmental improvement, and rural community development. SCS programs include:

- Conservation Programs. Under these programs the SCS (1) provides technical assistance through conservation districts to landowners and operators in carrying out locally adapted soil and water conservation programs; (2) conducts soil surveys to determine soil use potentials and conservation treatment needs; (3) conducts snow surveys in Western states to develop water supply forecasts; (4) operates plant materials centers to assemble and test promising plant species and encourage their use in conservation programs; (5) appraises the status and condition of soil, water, and related resources and trends in their use, designs long-range conservation programs with the aid of local soil conservation districts, and evaluates progress in meeting conservation needs; (6) assists producers in determining if their cropland or potential cropland is highly erodible wetland, wetland on which the conversion would have a minimal effect, or converted wetland; and (7) assists in preparing conservation compliance plans and installing appropriate conservation systems to maintain producers' eligibility for department program benefits.

- River Basin Surveys and Investigations. Cooperates with the Economic Research Service, the Forest Service, and other federal, state, and local agencies in conducting river basin surveys, flood plain management studies, and special studies of the Colorado River Basin.

- Watershed Planning. Administers investigations and surveys of proposed small watershed projects and assists sponsoring local organizations in developing of watershed plans.

- Watershed Protection and Flood Prevention. In cooperation with local sponsoring organizations, state and other public agencies, the SCS administers the installation of improvements to reduce erosion, floodwater, and sediment damage; to conserve, develop, utilize, and dispose of water and to prevent floods. (The Farmers Home Administration administers a loan program in conjunction with this effort to help finance the local share of these improvement costs.) The SCS also carries out emergency watershed protection.

- Great Plains Conservation. Administers a program designed to promote conservation and greater agricultural stability in the Great Plains, including cost-sharing under three- to ten- year contracts and technical assistance.

- Resource Conservation and Development. Conducts investigations and surveys to help local governments develop land and water conservation and use plans, and provides technical assistance. (The Farmers Home Administration administers a loan program in conjunction with this effort to help finance the local share of the costs of conservation and development projects.)

- Rural Abandoned Mine Program. Administers a program that assists land users in reclaiming abandoned or inadequately reclaimed coal-mined lands and water by providing technical assistance and cost-sharing ranging from 25 to 100 percent under five- to ten- year contracts.

- Other technical assistance. Provides technical assistance to the Farmers Home Administration in making soil and water conservation loans to landowners and operators. Assists landowners and operators in developing recreation areas and facilities on private land. Provides technical assistance to participants in the Agricultural Conservation Program, Rural Clean Water Program, Conservation Reserve Program, Colorado River Salinity Control Program, and Water Bank Program and develops the conservation plans that are the basis of long-term agreements between the Department landowners and the operators in these programs.

Department of the Army

Army Corps of Engineers. The Commanding General of the Army Corps of Engineers manages and executes the Civil Works Programs including: (1) research and development, planning, design, construction, operation and maintenance, and real estate activities related to rivers, harbors, and waterways; (2) administration of laws for protection and preservation of navigable waters and related resources such as wetlands; and (3) assistance in recovery from natural disasters.

Department of Commerce

Economic Development Administration. Provides assistance in areas of high unemployment, low income levels, or sudden and severe economic distress to generate new jobs, protect existing jobs, and stimulate commercial and industrial growth. Administers public works grants program for public and private nonprofit organizations and Indian tribes to help build or expand facilities essential to industrial and commercial growth, including water and sewer lines.

National Bureau of Standards. Conducts research providing groundwork for the nation's physical and technical measurement systems. Provides scientific and technological services to industry and government, such as measurement standards, test methods and technical data, to increase productivity and innovation, promote international competitiveness in American industry, ensure United States involvement in product standardization, maintain equity in trade, and promote product safety.

National Oceanic and Atmospheric Administration. Created to explore, map, and chart the global ocean and its living resources and to manage, use, and conserve those resources. Describes, monitors, and predicts conditions in the atmosphere, ocean, sun, and outer space environments. Conducts a program of management, research, and services related to the protection and rational use of the ocean and its living resources. Predicts tides, currents, and the state of the oceans. Conducts research and development on alternatives to ocean dumping. Develops national policies on ocean mining and energy. Promotes wise and balanced management of the nation's coastal zone. Issues warnings against impending destructive natural events. Assesses the consequences of inadvertent environmental modification over time. Manages and disseminates long-term environmental information. Administers and directs the National Sea Grant college program by providing grants to institutions for marine research, education, and advisory services.

National Weather Service. The agency within the National Oceanic and Atmospheric Administration that reports the weather of the United States and its possessions and provides weather forecasts to the general public; issues warnings against destructive natural events such as hurricanes, tornadoes, floods, and tsunamis; and provides services in support of aviation, marine activities, agriculture, forestry, urban air-quality control, and other weather-sensitive activities. The agency also monitors and reports all non-federal weather modification activities conducted in the United States.

Department of Energy

Assistant Secretary for Conservation and Renewable Energy. Responsible for formulating and directing programs designed to increase the production and use of renewable energy and improve the energy efficiency of transportation, buildings, industrial systems, and related processes through support of long-term, high-risk research and development activities. Also responsible for administering financial assistance programs for state energy planning, weatherization of housing owned by the poor and disadvantaged, and implementation of energy conservation measures by schools and hospitals, local units of government, and public care institutions.

Federal Energy Regulatory Commission. An independent, five-member commission with authority for licensing hydroelectric power plants.

Federal Power Administrations. Five federal power administrations market electrical power:

- Bonneville Power Administration. Markets electric power and energy from federal hydroelectric projects in the Pacific Northwest constructed and operated by the Army Corps of Engineers and the Bureau of Reclamation. Also responsible for energy conservation, renewable resource development, and fish and wildlife enhancement. Implements the Columbia River Treaty with Canada in cooperation with the Corps of Engineers.

- Southeastern Power Administration. Transmits and disposes of surplus electric power and energy generated at federal reservoir projects.

- Alaska Power Administration. Operates and markets power for the Ekluta and Snettisham Hydroelectric Projects in Alaska.

- Southwestern Power Administration. Transmits and disposes of electric power and energy generated at federal reservoir projects. Also conducts and participates in comprehensive planning of water-resource development in the Southwest.

- Western Area Power Administration. Markets electric power generated by the Bureau of Reclamation, the U.S. Army Corps of Engineers, and the International Boundary and Water Commission.

Department of Health and Human Services

Agency for Toxic Substances and Disease Registry. Collects, maintains, analyzes, and disseminates information relating to serious diseases, mortality, and human exposure to toxic or hazardous substances. Assists the Environmental Protection Agency in identifying hazardous waste substances to be regulated. Develops scientific and technical procedures for evaluating public health risks from hazardous substance incidents, and for developing recommendations to protect public health and worker safety and health in instances of exposure or potential exposure to hazardous substances. Arranges for program support to ensure adequate response to public health emergencies.

National Center for Toxicological Research. Studies the biological effects of potentially toxic chemical substances found in the environment, emphasizing the determination of the health effects resulting from long-term, low-level exposure to chemical toxicants and the basic biological processes for chemical toxicants to animal organisms. Develops improved methodologies and test protocols for evaluating the safety of chemical toxicants and the data that will facilitate the extrapolation of toxicological data from laboratory animals to man.

National Institute of Environmental Health Sciences. Conducts and supports fundamental research on the effects of chemical, biological, and physical factors in the environment on the health and well-being of man.

Department of Housing and Urban Development

Assistant Secretary for Community Planning and Development. Responsible for the following programs:

- Community Development Block Grant Program. Provides grants to communities for development activities such as neighborhood revitalization, economic development, and the provision of improved community facilities and services, including water and sewer facilities.

- Loan Guarantees. Guarantees loans to communities to finance the acquisition of real property, rehabilitation of publicly owned real property, and economic development activities undertaken by nonprofit or for-profit entities.

- Environmental Quality. Develops standards, policies, and procedures for environmental assessments and impact statements, and compliance with laws and executive orders on floodplains, wetlands, aquifers, endangered species, and other resources. Provides technical assistance to communities in environmental and land-use planning, and in environmental management practices.

Department of the Interior

Assistant Secretary for Water and Science. Oversees the programs of the Bureau of Reclamation, Bureau of Mines and the Geological Survey. Duties include water resource evaluation and analysis, oversight of the Department's irrigation drainage water quality program, and development, management, and conservation of the Nation's water supply and support of cost-sharing techniques for the development and management of water supplies in 17 Western states.

Bureau of Indian Affairs. Actively encourages and trains Indian and Alaskan natives to manage their own affairs under the trust relationship to the federal government. The Bureau works with native Americans in the development and implementation of programs for their economic advancement and for full utilization of their natural resources consistent with the principles of resource conservation.

Bureau of Land Management. Manages 270 million acres of the nation's public lands, including wild and scenic rivers, designated conservation and wilderness areas, and open space. Also manages watersheds to protect soil and enhance water quality.

Bureau of Mines. Collects statistical and economic information on nonfuel mineral resource development and conducts research on nonfuel minerals technology, including research on the abatement of pollution caused by mineral extraction and processing operations.

Bureau of Reclamation. Responsible for hydroelectric power generation, river regulation and flood control, outdoor recreation opportunities, and enhancement and protection of fish and wildlife habitat in 17 Western states. Develops plans for the conservation and wise use of water. Operates, maintains, repairs and rehabilitates existing flood control and hydroelectric facilities and designs and constructs new facilities. Administers loans to states and local entities for construction and rehabilitation of water supply systems. Prepares environmental statements for proposed federal water resource projects. Provides technical assistance to foreign countries for water resource development.

Fish and Wildlife Service. Conserves, protects, and enhances fish and wildlife and their habitats for the continuing benefit of the American people. Promotes habitat preservation through biological monitoring, surveillance of pesticides, heavy metals, and thermal pollution; assessment of the environmental impact of projects such as hydroelectric dams, stream channelization, and dredge and fill operations; and review of environmental impact statements. Provides federal aid to states and territories for projects designed to conserve, develop, and enhance fish and wildlife resources.

Geological Survey. Identifies the nation's land, water, energy, and mineral resources and water power potential. Classifies federally owned lands for mineral and energy resources, and for water power potential also determines the water supply of the United States, investigates natural hazards, and conducts the National Mapping Program. Programs and activities of the Water Resources Division are:

- Acid Rain Program
- Coordination of Federal Water-Data Acquisition Activities
- District Programs
- Environmental Affairs Program (EAP

- Federal-State Cooperative Program
- NAWDEX (National Water Data Exchange)
- National Water-Quality Assessment (NAWQA)
- National Water-Quality Networks Program
- National Water Summary Program
- National Water-Use Information Program
- Nuclear Waste Hydrology Program
- Other Federal Agency (OFA) Programs
- Regional Acquifer-System Analysis (RASA) Program
- Scientific Publications Program
- State Water Research Institutes Program
- Toxic Sunstances Hydrology Program (TSHP)
- Water-Data Program
- Water Information Transfer Program (WITP)
- Water Research Grants Program
- WATSTORE (National Water Data Storage and Retrieval System)
- WRSIC (Water Resources Scientific Information Center)

Minerals Management Service. Responsible for the Department's Outer Continental Shelf leasing program, including resource evaluation and classification, environmental review, leasing activities, lease management, and inspection and enforcement.

National Park Service. Administers an extensive system of national parks, monuments, historic sites, and recreation areas, including riverways, seashores, and reservoirs. Also administers the state portion of the Land and Water Conservation Fund, and provides planning and technical assistance for the National Wild and Scenic Rivers System.

Department of Justice

Land and Natural Resources Division. Represents the United States in litigation involving public lands and natural resources, environmental quality, Indian lands and claims, and wildlife resources. In the area of environmental statutes, brings civil and criminal enforcement cases primarily on behalf of the Environmental Protection Agency for the control and abatement of pollution of air and water resources and the regulation and control of toxic substances and hazardous wastes.

Department of State

Bureau of Oceans and International Environmental and Scientific Affairs. Principally responsible for the Department's formulation and implementation of United States government policies and proposals regarding the scientific and technological aspects of United States relations with other countries and international organizations. Responsible for managing a broad range of foreign policy issues and significant global problems related to oceans, fisheries, environment, population, nuclear technology, new energy technology, and cooperative efforts dealing with the application and transfer of technology. Provides policy guidance to the United States oceanic, environmental, scientific, and technological communities on activities and programs affecting foreign policy issues.

Department of Transportation

United States Coast Guard. The primary federal maritime law enforcement agency. Enforces federal laws and treaties and other international agreements on, over, and under the high seas and waters subject to the United States jurisdiction. Enforces the Federal Water Pollution Control Act and other laws relating to the protection of the marine environment. Through its National Response Center, coordinates the reporting, investigation, and cleanup of oil and hazardous substance spills.

Saint Lawrence Seaway Development Corporation. A United States government-owned enterprise responsible for the development, operation, and maintenance of the Saint Lawrence Seaway between Montreal and Lake Erie.

INDEPENDENT ESTABLISHMENTS AND GOVERNMENT CORPORATIONS

Environmental Protection Agency.

Responsible for protecting and enhancing the environment under the laws enacted by Congress. The agency's mission is to control and abate pollution in the areas of air, water, solid waste, pesticides, radiation, and toxic substances. EPA's mandate is to mount an integrated, coordinated attack on environmental pollution in cooperation with state and local governments. It emphasizes proper integration of a variety of research, monitoring, standard-setting, and enforcement activities. EPA also reinforces efforts among other federal agencies with respect to the effect their operations have on the environment. EPA's ten regional offices represent the agency's commitment to the development of strong local programs for pollution abatement.

Assistant Administrator for Water. Organized into Office of Water Enforcement and Permits, Office of Water Regulations and Standards, Office of Municipal Pollution Control, Office of Drinking Water, Office of Marine and Estuarine Protection, and Office of Groundwater Protection. Additional water quality responsibilities belong to the Assistant Administrator for Enforcement and Compliance Monitoring and the Assistant Administrator for Research and Development. EPA's water quality activities represent a coordinated effort to restore the nation's waters. The functions of the water program include: (1) development of national programs, technical policies, and regulations for water pollution control and water supply; (2) groundwater protection; (3) marine and estuarine protection; (4) enforcement of standards; (5) water quality standards and effluent guidelines development; (6) technical direction, support, and evaluation of regional water activities; (7) development of programs for technical assistance and technology transfer; and (8) provision of training in the field of water quality.

Federal Emergency Management Agency

Created to provide a single point of accountability for all federal emergency preparedness, mitigation, and response activities. The Agency is chartered to enhance the multiple use of emergency preparedness and response resources at the federal, state, and local levels of government for a full range of emergencies--natural, technological, and attack-related--and to integrate into a comprehensive framework activities concerned with hazard mitigation, preparedness planning, relief operations, and recovery assistance. The agency's Federal Insurance Administration administers the National Flood Insurance Program.

General Services Administration

Establishes policy and provides for the government a system for managing its property and records, including construction and operation of buildings, transportation, traffic, and communications management, stockpiling of strategic materials, and the management of the government-wide automatic data processing resources program.

Public Buildings Service. Under the public utilities program, the Office of Procurement of the PBS reviews public utility rate schedules to determine the adequacy of the rates with respect to the government as a consumer; negotiates utility rates and contracts for general government use and for numerous special situations; and, on behalf of federal agencies, provides advice and expert testimony in proceedings before regulatory bodies when the government's interest as a consumer needs to be protected. In addition, the office issues government-wide standards concerning the procurement, use, and conservation of utilities for regulation and management guidance in this area.

Interstate Commerce Commission

Regulates carriers engaged in transportation in interstate commerce and in foreign commerce within the United States Grants the right to operate to water carriers.

Panama Canal Commission

Manages, operates, and maintains the Panama Canal and its works, installations, and equipment, and provides for the orderly transit of vessels through the canal.

Small Business Administration

Loan Programs. Provides guaranteed, direct, or immediate participation loans to small business concerns to help finance plant construction, conversion, or expansion and acquire equipment, facilities, machinery, supplies, or materials. Provides loans to victims of floods, riots, civil disorders and other catastrophes to aid in the repair, rebuilding, or replacement of homes, businesses, or other property. Provides loans to small businesses that have sustained substantial injury resulting from natural disasters.

Pollution Control Financing Program. Provides 100 percent guarantees of loans, leases, or other contracts to assist small businesses obtain long-term financing of pollution control equipment.

Tennessee Valley Authority

A United States government-owned corporation that conducts a unified program of resource development for the advancement of economic growth in the Tennessee River valley region. Activities include flood control, navigation development, hydroelectric power production, and research and development of watershed protection and fish and wildlife habitat. Also operates Land Between the Lakes, a demonstration project in outdoor recreation, environmental education, and natural resource management.

QUASI-OFFICIAL AGENCIES

Smithsonian Institution

Smithsonian Environmental Research Center. Conducts research on the ecology of land/water interactions.

Smithsonian Tropical Research Institute. Conducts research, biology, and supports education and conservation efforts in tropical biology through inland and marine biology laboratories in the Republic of Panama, and through research in other tropical areas of the world. Operates the Barro Colorado Nature Monument in the Republic of Panama.

BILATERAL ORGANIZATIONS

International Boundary and Water Commission, United States and Mexico.

Implements existing treaties dealing with boundary and water matters affecting both countries, including the distribution between the two countries of the waters of the boundary rivers, control of floods on the boundary rivers, regulation of the boundary rivers by joint storage works to enable utilization of the waters in both countries, improvement of the water quality of boundary rivers, sanitation measures, and use of the waters in the boundary section of the Rio Grande to jointly develop hydroelectric power.

International Joint Commission, United States and Canada

Prevents disputes over the use of boundary waters and settles questions between the two countries involving rights, obligations, or interests along the common frontier. Also monitors, evaluates, and encourages compliance with the Great Lakes Water Quality Agreement of November 22, 1978.

Source: Adapted from Office of the Federal Register, National Archives and Records Administration, *The United States Government Manual 1988/1989*, Revised June 1, 1988 (Washington, DC: U.S. Government Printing Office, 1988). Programs of the U.S. Geological Survey are derived from U.S. Geological Survey, *Water Resources Division Information Guide* (Washington, DC: U.S. Geological Survey, 1988).

INTERSTATE AGENCIES AFFECTING WATER RESOURCE POLICY

ADVISORY AGENCIES

New England Governors' Conference, Inc. (1936)

Member States: Connecticut
Maine
Massachusetts
New Hampshire
New York
Rhode Island
Vermont

Interstate Commission on the Potomac River Basin (1940)

Member States: District of Columbia
Maryland
Pennsylvania
Virginia
West Virginia

Great Lakes Commission (1955)

Member States: Illinois
Indiana
Michigan
Minnesota
New York
Ohio
Pennylvania
Wisconsin

Klamath River Compact Commission (1957)

Member States: California
Oregon

Western States Water Council (1965)

Member States: Alaska
Arizona
California
Colorado
Montana
Nevada
New Mexico
North Dakota (a)
Oregon
South Dakota (a)
Texas
Utah
Washington
Wyoming

Missouri Basin States Association (1981)

Member States: Colorado
Iowa
Kansas
Missouri
Montana
Nebraska
North Dakota
South Dakota
Wisconsin
Wyoming

Ohio River Basin Commission (1981)

Member States: Illinois
Indiana
Kentucky
Maryland
North Carolina
Ohio
Pennsylvania
Virginia
West Virginia

Upper Mississippi River Basin (1981)

Member States: Illinois
Iowa
Minnesota
Missouri
Wisconsin

AGENCIES WITH ENFORCEMENT POWERS

Interstate Sanitation Commission (1936)
Member States: Connecticut
New Jersey
New York

New England Interstate Water Pollution Control Commission (1947) (b)
Member States: Connecticut
Maine
Massachusetts
New Hampshire
New York (c)
Rhode Island
Vermont

Ohio River Valley Sanitation Commission (1948)
Member States: Illinois
Indiana
Kentucky
Ohio
Pennsylvania
Virginia
West Virginia

Upper Colorado River Commission (1948) (d)
Member States: Colorado
New Mexico
Utah

Delaware River Basin Commission (1961)
Member States: Delaware
New Jersey
New York
Pennsylvania

Tahoe Regional Planning Agency (1969)
Member States: California
Nevada

Susquehanna River Basin Commission (1971)
Member States: Maryland
New York
Pennsylvania

Source: The Council of State Governments, *Book of the States, 1988-89 Edition* (Lexington, KY: The Council of State Governments, 1988), 412-13.

(a) Associate member.
(b) Primarily advisory; has the power to enforce water quality regulations on interstate rivers.
(c) Not a formal member; cooperates on water issues through the New England/ New York Water Council, which is part of this conference.
(d) Allocates water from the Colorado River.

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